

**DEVELOPMENT OF THE DISPOSAL TECHNOLOGY
RESEARCH COMPONENT OF THE
NATIONAL URANIUM TAILINGS PROGRAM**

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FINAL REPORT

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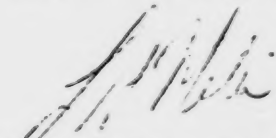
Dear Mr. Haw:

I am pleased to submit my report entitled "Development of the Disposal Technology Research Component of the National Uranium Tailings Program".

The report, done under Contract Number OSQ82-00252, summarizes the existing conditions at uranium tailings sites in Canada and describes various waste disposal technologies that exist for uranium tailings. Recommendations are made with respect to potential research avenues for the disposal technology component of the N.U.T.P.

I hope this work will meet with your approval and I remain available to answer any questions as required.

Respectfully yours,



L.A. Melis, P.Eng.

LAM:dm
att.

DEVELOPMENT OF THE DISPOSAL TECHNOLOGY

RESEARCH COMPONENT OF THE

NATIONAL URANIUM TAILINGS PROGRAM

Final Report

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March 1983

Saskatoon, Canada



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Development of the Disposal Technology
Research Component of the
National Uranium Tailings Program

ABSTRACT

The National Technical Planning Group on Uranium Tailings Research, organized by CANMET in 1980, recommended the establishment of a National Uranium Tailings Program to develop research on the long-term abandonment of uranium mine tailings. This report deals with the disposal technology component of this program and attempts to provide recommendations with respect to potential research avenues in this area.

A description of uranium tailings in Canada is provided in order to identify the current situation with uranium tailings management. Uranium mining sites described include the Elliot Lake and Bancroft area of Ontario, the northern Saskatchewan properties and the two abandoned sites in the North West Territories. The description of the sites was facilitated by subdividing the tailings into inactive sites, active sites, new tailings sites and areas of tailings in a close-out situation.

The site-specific nature of the different tailings areas has provided some insight into possible research avenues but an assessment of waste disposal technologies has afforded the various options available for further study. The different technologies described include site selection, surface and subsurface impoundment techniques, the use of liners, flow barriers, effluent treatment, tailings modification methods, in-situ leaching, reclamation and waste rock disposal.

Although numerous research recommendations have been made it was concluded that only high-potential research avenues should be pursued at the onset of the program.

Research into subsurface disposal options should take precedence over surface tailings disposal due to the potential of providing long-term, permanent, disposal of tailings in a below-ground environment. The use of layered tailings, with the possibility of enhancement by mechanical sand-slime separation, has been identified as the more promising surface disposal option.

Investigations are necessary into the physical and chemical aspects of liners and their long-term integrity. Research on removal of radionuclides needs to be continued in light of the benefits of innocuous tailings for long-term surface disposal. Research into the prevention of pyrite oxidation for Elliot Lake tailings continues to be an important area due to the long-term potential of acid generation. Pyrite removal for acid production should be pursued in light of the benefits of pyrite-free tailings.

The use of in-situ leaching is presented as a novel method worth assessing for uranium properties in northern Saskatchewan since solid tailings would not be produced in this type of operation.

Reclamation studies should be continued, or initiated, at the various abandoned sites. Present natural, ecological processes that are occurring at abandoned sites should be used as a guide for developing future reclamation plans.

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1.0 INTRODUCTION

Uranium tailings have been the subject of much attention over the last decade due to the potential environmental problems associated with them. The main items of concern have been the radionuclide content of tailings and their potential release to the environment as well as the acid-generating capacity of tailings for certain tailings impoundments.

A National Technical Planning Group on Uranium Tailings Research was organized by CANMET in 1980 to study the problem on a national basis. From their recommendations in a report issued in September 1981, the National Uranium Tailings Program (N.U.T.P.) was established along the guidelines recommended by the Planning Group for developing research on the long-term abandonment of uranium mine tailings.

Recommendations in the report concluded that the N.U.T.P. should consist of three main components; a sampling program, a modelling program and a disposal technology program. This report deals specifically with the disposal technology component and attempts to provide some recommendations with respect to potential research avenues in this area.

There have been numerous reports, papers and documents published on solids disposal technology for uranium waste management and these have been referenced extensively. The list of references at the end of this report is not meant to include all the pertinent information that is available on the subject.

The report concentrates on the tailings aspects of uranium operations in Canada. A brief description of each tailings site in Canada is provided in order to identify the current situation for uranium tailings management. This is followed by a review of individual aspects of uranium tailings disposal technology in order

to assess the various alternatives available for consideration.

An overall assessment of this information then allows recommendations to be made with respect to research avenues related to waste disposal technology. Although some form of priority can be allocated to these potential research areas, the proposed modelling program will be required to identify the more promising research areas with potential for long-term abandonment of uranium tailings.

2. DESCRIPTION OF TAILINGS AREAS

2.1 Introduction

There are several types of uranium tailings areas in Canada which require consideration. These include areas of inactive tailings, areas of tailings in a close-out situation, active tailings sites and new tailings sites for new operations coming on stream.

The location of uranium tailings areas and some of the significant uranium deposits in Canada are shown in Figure 1. Existing properties are located in the Elliot Lake and Bancroft area in Ontario (Figure 2) and in northern Saskatchewan (Figure 3).

Due to the site-specific nature of uranium tailings a description of each area is warranted with respect to the characteristics of the tailings material and with regards to the site conditions that exist.

2.2 Tailings Characteristics

Due to the varying nature of the ores in the Canadian uranium deposits, the tailings characteristics differ for the various sites.

Tailings in the Elliot Lake area of Ontario are acid-generating due to their high pyrite content and contain radium, thorium and uranium as radionuclide contaminants. The tailings in the Bancroft area contain the same radionuclides but are not acid-generating due to their very low pyrite content.

The ores in northern Saskatchewan have been found to contain very little pyrite and negligible amounts of thorium. On the

- Existing Tailings Sites
- New or Potential Sites

1. Elliot Lake
2. Agnew Lake
3. Bancroft
4. Beaverlodge
5. Cluff Lake
6. Rabbit Lake
7. Port Radium
8. Rexpär
9. Beaverdell (Blizzard)
10. Key Lake
11. Midwest, Dawn, McClean
12. Baker Lake
13. Michelin
14. Rayrock

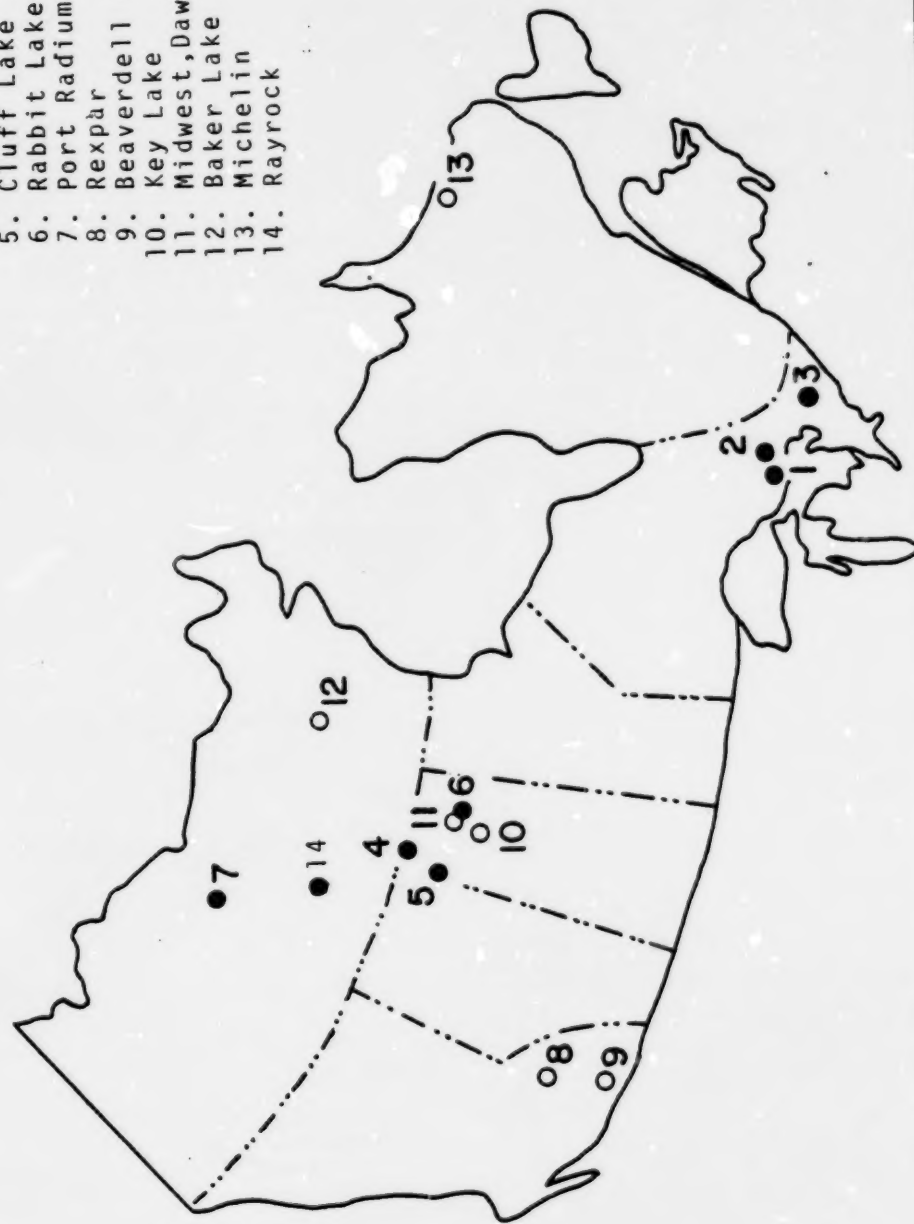


Figure 1 - Location of Uranium Areas in Canada
(adapted from planning Group Report, September 1981)

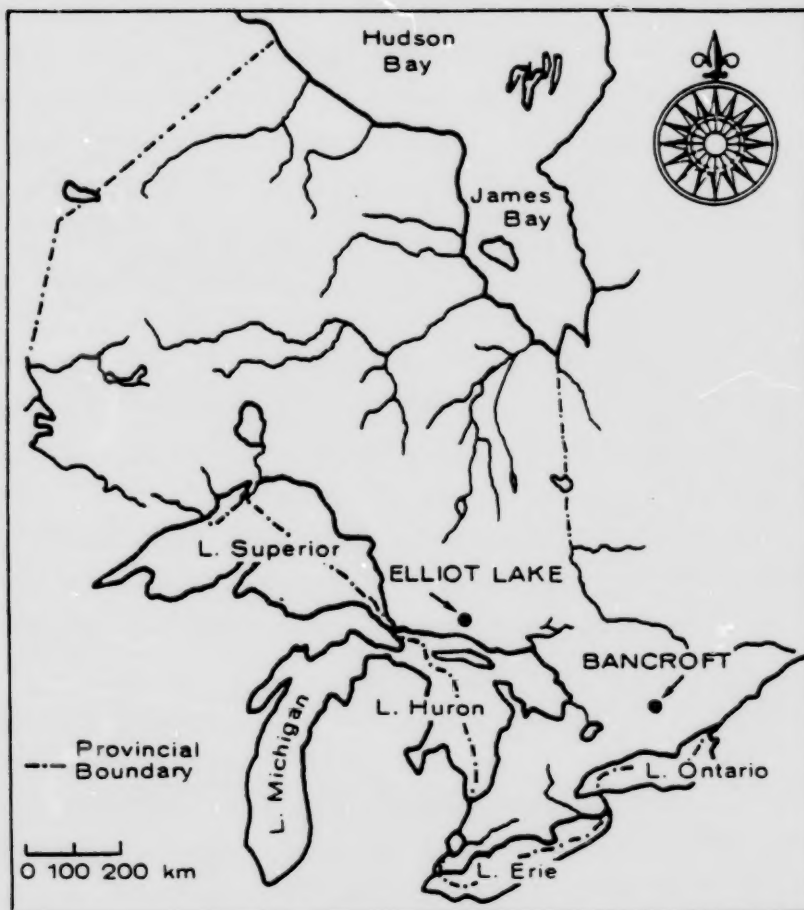


Figure 2

LOCATION OF ELLIOT LAKE AND BANCROFT, ONTARIO
(from Kalin 1983)

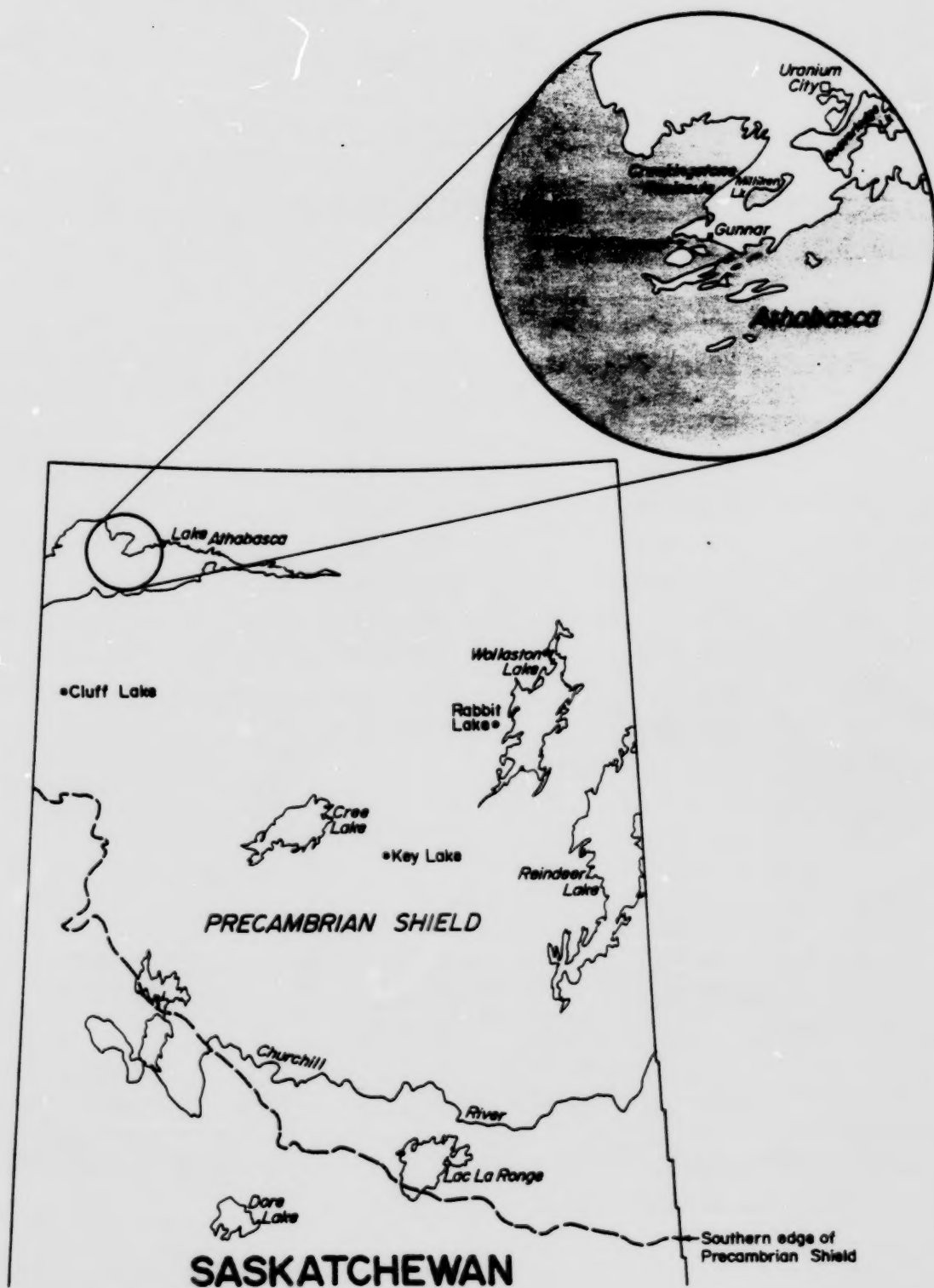


Figure 3 - Northern Saskatchewan Uranium Properties.
(from Tones 1982)

other hand, uranium grades are very high and hence the radium content in the tailings will be higher than that found in Ontario deposits. Some of the deposits in Saskatchewan contain substantial amounts of heavy metals and arsenic while others (the Cluff Mining and Rabbit Lake deposits) are relatively arsenic free. The Beaverlodge deposit is unique due to its high calcite content. Except for one abandoned site, north of Lake Athabasca, the tailings in Saskatchewan are not anticipated to be acid-generating.

2.3 Inactive Tailings

A list of inactive tailings in Canada is provided in Table 1. This list includes the Lorado and Gunnar tailings in northern Saskatchewan (Figure 4) the Port Radium and Rayrock tailings in the North West Territories (N.W.T.), the Bicroft and Dyno areas near Bancroft, Ontario (Figure 5) and the Nordic, Lacnor, Stanrock, Spanish American and Pronto tailings sites in the Elliot Lake area of northern Ontario (Figure 6).

2.3.1 Lorado

The Lorado tailings are located approximately 10 km west of Uranium City, Sask. on the west shore of Nero Lake (Figure 4). A custom uranium mill was operated from 1957 to 1960 by Lorado Uranium Mines Ltd. using an acid-leach circuit, ion exchange with NaCl elution and magnesium diuranate precipitation. The tailings, approximately 360,000 tonnes, were deposited at pH 2 directly to Nero Lake (Figure 7). Studies in this area have been carried out by Ruggles et al, 1978; Swanson and Abouguendia 1981; Whiting et al, 1982 and Kalin, 1982.

The general site conditions that exist at Lorado have been determined as follows:

TABLE 1INACTIVE TAILINGS

<u>SITE</u>	<u>DATE OF OPERATION</u>	<u>TOTAL TONNES</u> <u>(APPROXIMATE)</u>	<u>APPROX. AREA</u> <u>(HECTARES)</u>
Lorado, Sask.	1957-1960	360,000	14
Gunnar, Sask.	1955-1964	5,500,000	45
Port Radium, N.W.T.	1933-1960	910,000	?
Rayrock, N.W.T.	1957-1959	80,000	?
Bicroft, Ont.	1958-1963	2,000,000	8
Dyno, Ont.	1958-1960	360,000	3
Faraday, Ont.	1957-1962	1,800,000	16
Nordic, Ont.	1957-1968	11,000,000	101
Lacnor, Ont.	1957-1960	2,700,000	24
Stanrock, Ont.	1958-1964	8,000,000	71
Spanish American, Ont.	1958-1959	450,000	5
Pronto, Ont.	1955-1966	2,100,000	47

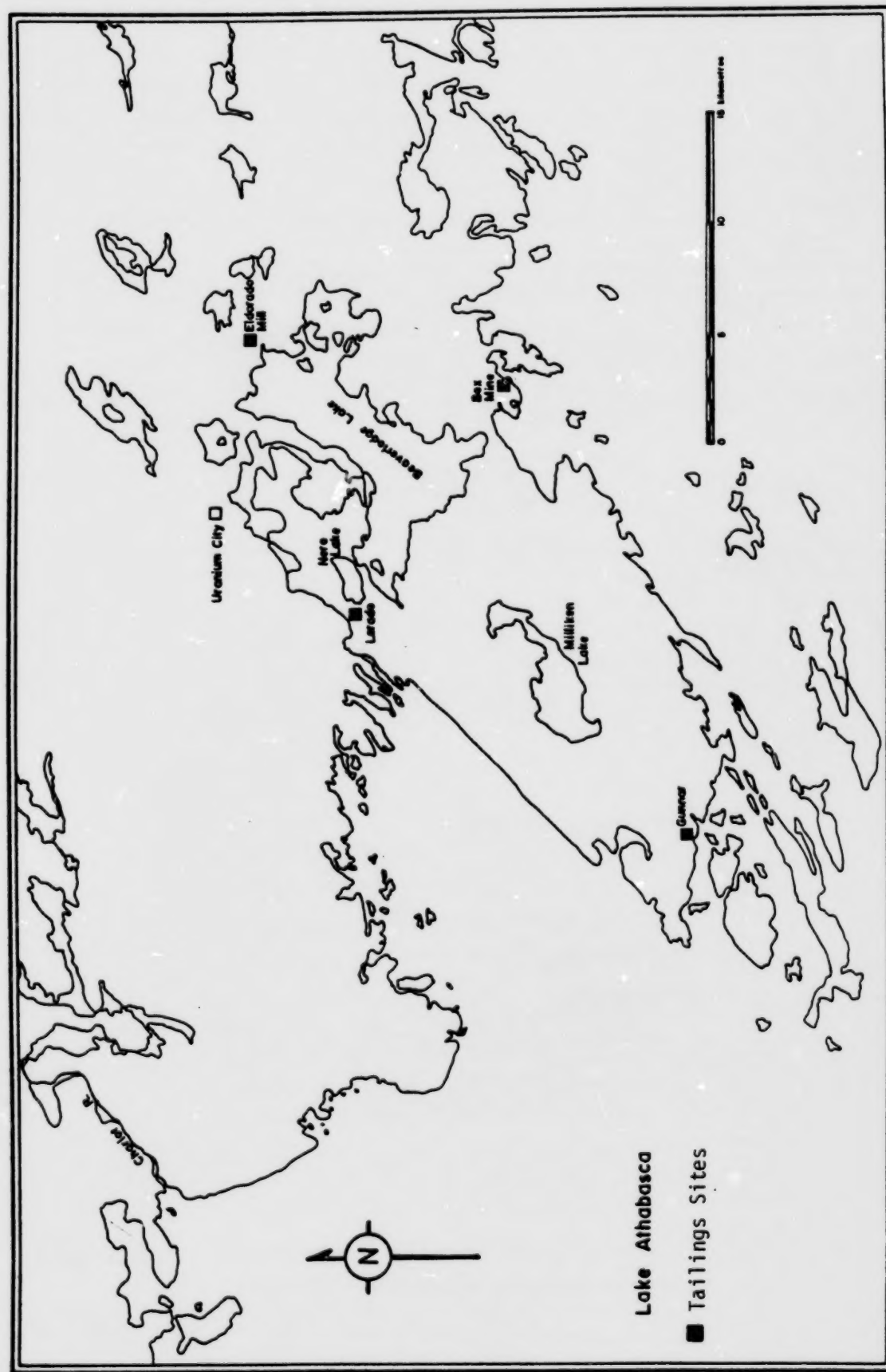


Figure 4 - Location of Lorado and Gunnar Tailings Sites.
(from Swanson, Abouguendia, 1981)

Scale: 1 cm = 1010 m

LEGEND

- 11. Madawaska
- 12. Auger Lake
- 13. Biccroft Swamp
- 14. Biccroft Proper
- 15. Dyno

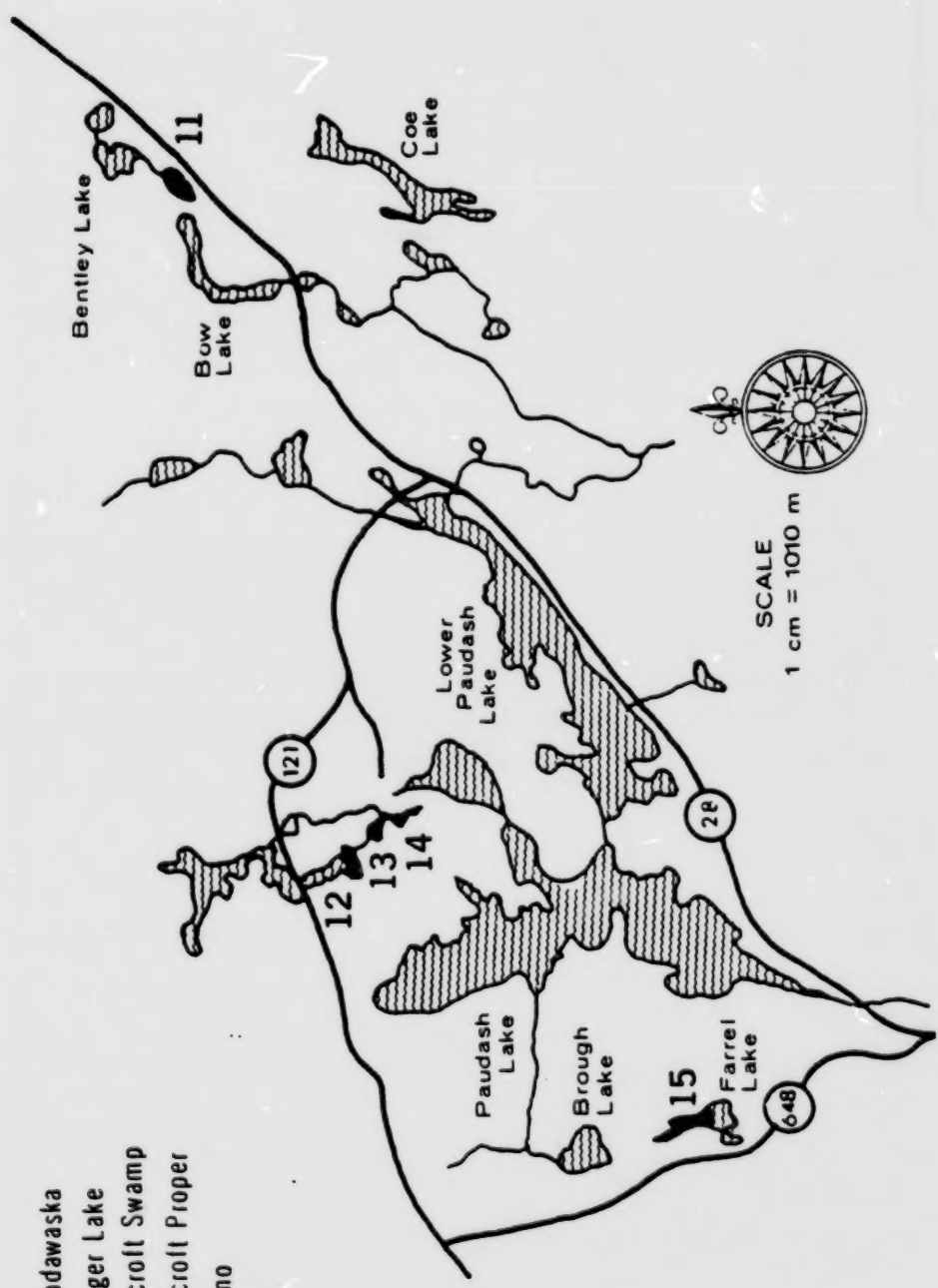


Figure 5 Bancroft Area Tailings Sites
(Kalin 1983)

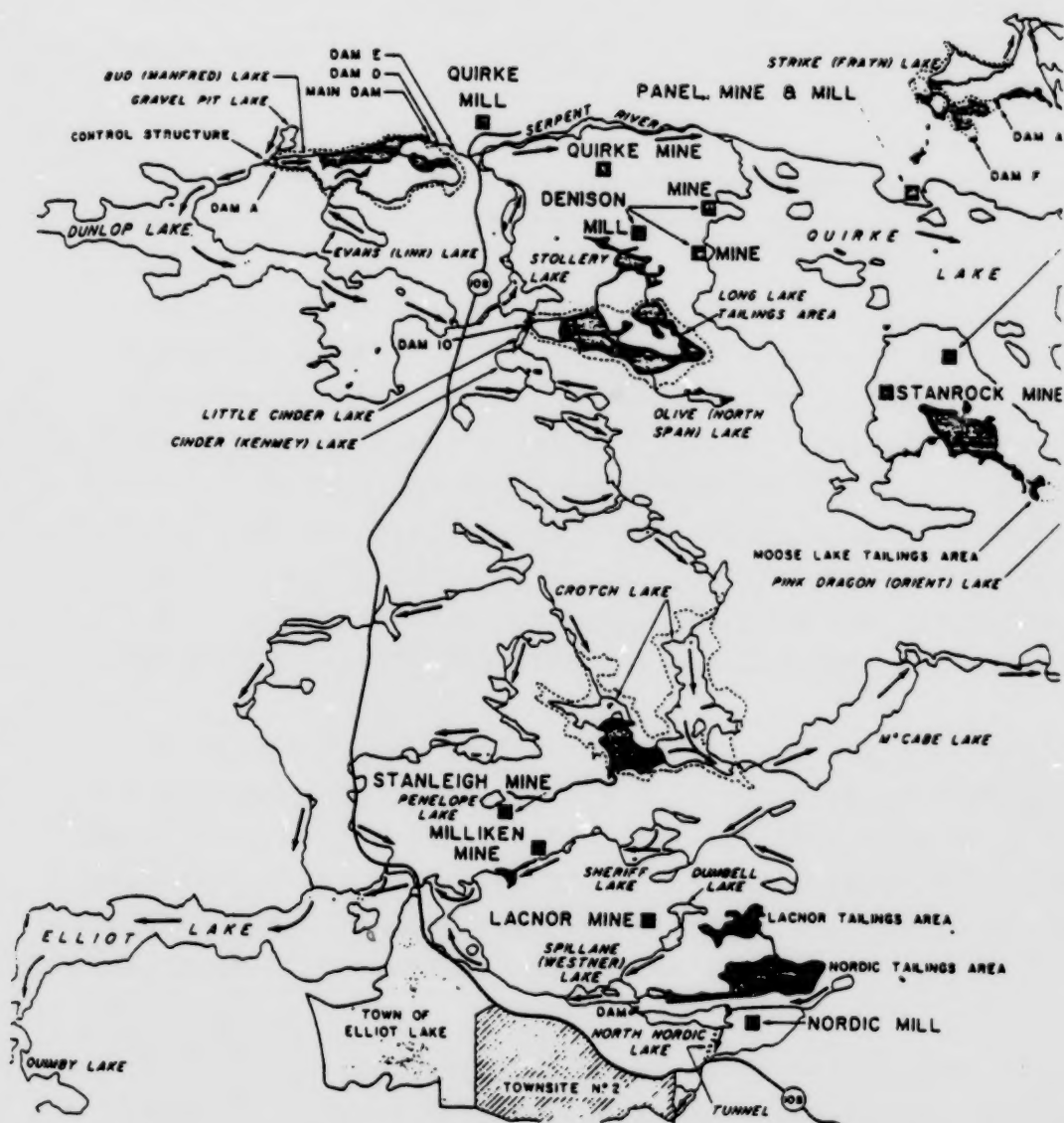


Figure 6 - Elliot Lake Area Tailings Sites
(from Environmental Assessment Board, 1979)

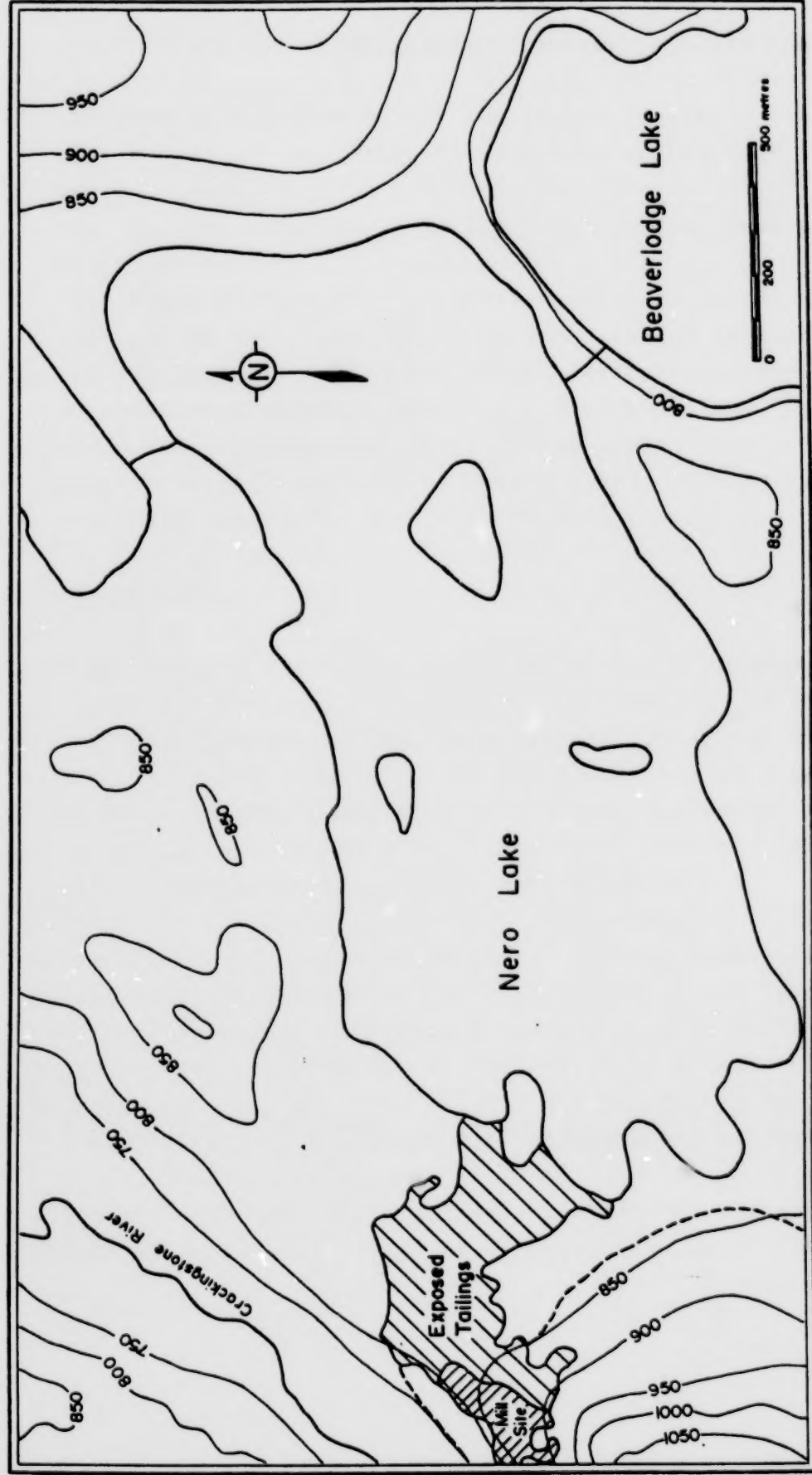


Figure 7 - Details of the Lorado Tailings Site
(from Swanson, Abouguendia, 1981)

- the tailings are pyritic and acid generating (pH 3.5).
- there is extensive layering of coarse and fines due to the method of tailings deposition that was practiced.
- the exposed surface layers are red in colour and cemented with oxidized iron.
- natural revegetation is sparse.
- wind erosion is apparent on the drier, coarse areas.
- acid generation in submerged tailings is minimal.
- water erosion is apparent in the lower part of the tailings area.
- a precipitate plume high in radionuclides extends into Hansen Bay through a berm between Nero Lake and Beaverlodge Lake.
- the moss carpet on the lake bottom is acid tolerant and is still growing. It is acting as a concentration sink for some of the cations being released by the tailings.
- the tailings, moss carpet and Nero Lake water have reached a steady-state and are in equilibrium.
- Nero Lake has not undergone any major changes in the last 8 years.
- the berm(land bridge) between Nero Lake and Hansen Bay may be acting as a barrier for the contaminants in Nero Lake.

It is apparent then that the chemical and physical interactions occurring in the Laredo tailings area are not well understood. Although the tailings and Nero Lake have reached equilibrium the long-term effect of these tailings through Beaverlodge Lake will need to be better understood. Some of the items that could be considered for further investigations include:

- the interactions that are occurring in Nero Lake, and through the berm between Nero Lake and Beaverlodge Lake, with regards to uptake of cations being released from the tailings.

- the contribution to contaminant release from the submerged tailings.
- the chemistry of the Ra 226 and cation uptake in the moss carpet on the bottom of Nero Lake and through the berm.
- the co-precipitation of Ra 226 in the precipitate plume in Hansen Bay.
- the effect of possible reclamation measures to the Lorado tailings on the steady-state system existing in Nero Lake and its potential in increasing contaminant release caused by a possible drastic change to a stable system.
- an impact assessment of the existing conditions and the possibility of improving on the stability of Nero Lake to provide a long-term, stable tailings area.

2.3.2 Gunnar

The Gunnar site is located 25 km southwest of Uranium City on the north shore of Lake Athabasca (Figure 4). A conventional acid leaching circuit was operated by Gunnar Mines Ltd. from 1955 to 1964 with the unneutralized tailings dumped into Mudford Lake. Some mine backfill of coarse tailings was also carried out at one time during the operation. A total of 5,500,000 tonnes of tailings were produced.

Mudford Lake basin eventually filled and additional tailings flowed north by gravity through 2 small lakes and into Langley Bay of Lake Athabasca (Figure 8). Studies in this area have been carried out by Swanson, Ruggles and Kalin.

The general site conditions for this area are as follows:

- the tailings contain very little pyrite with the pH being neutral or slightly alkaline.

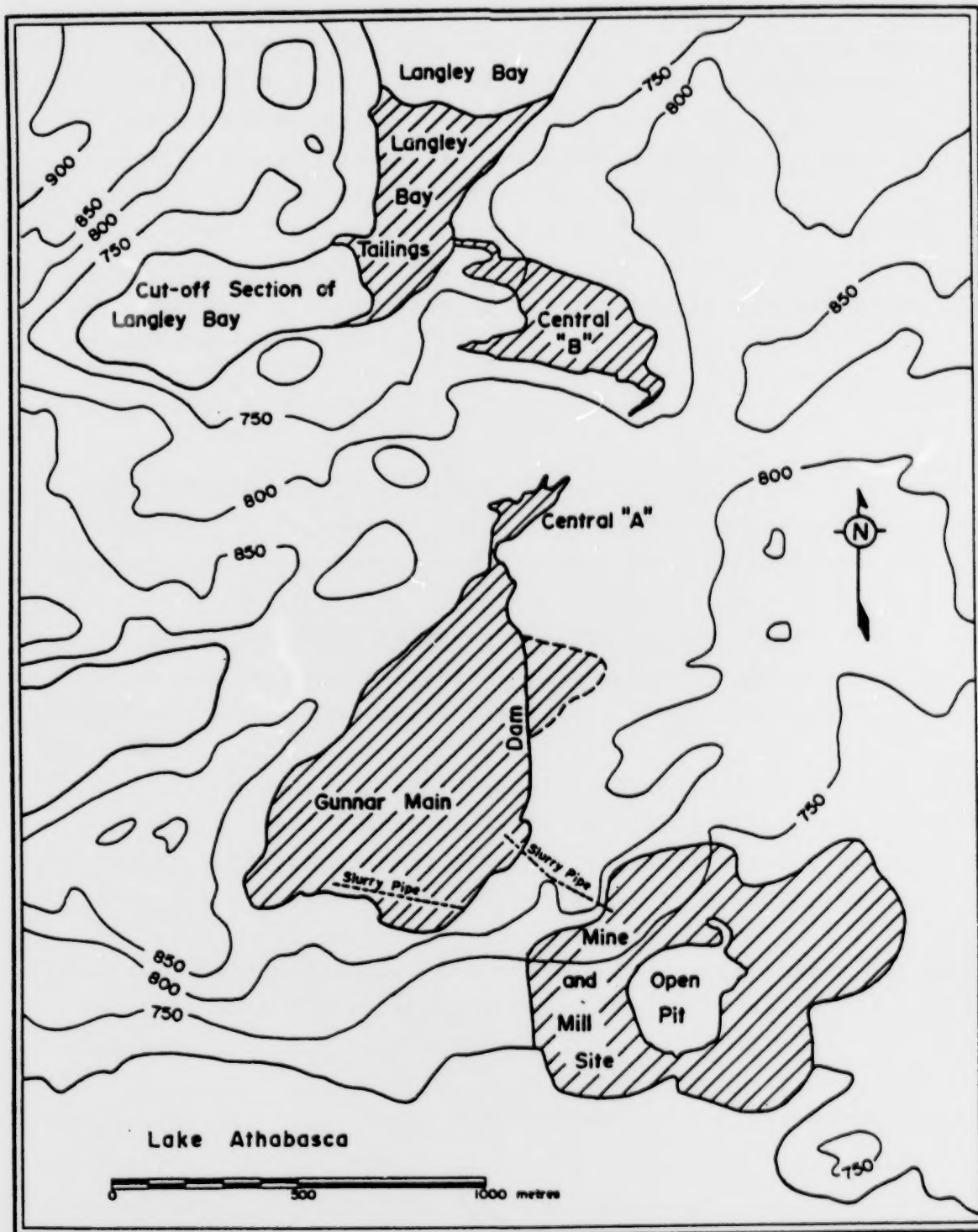


Figure 8 - Detail of the Gunnar Tailings Site.
(from Swanson, Abouguendia, 1981)

- the majority of the tailings are in the Gunnar Main area. These tailings are mostly dry with the upper portion subject to wind erosion.
- the "Central A" tailings are overgrown and the "Central B" tailings are dry and overgrown.
- the tailings delta in Langley Bay consist of fine tailings in the lake which closes off an arm of Langley Bay.
- the main factors limiting the spread of vegetation is surface instability and lack of moisture.
- the Langley Bay tailings are contributing to suspended solids, dissolved solids and radionuclides in Lake Athabasca (12-16pCi/L Ra²²⁶ in the bay in 1978).

A condition site-specific to the Gunnar area is the flooded open-pit and the waste rock piles that are present. The open-pit and underground workings were flooded by Lake Athabasca and in 1966 the open channel was closed leaving an isolated, flooded pit. A study by Tones (1982) indicated the following:

- there are five different strata in the 110 m deep open-pit.
- concentration of radionuclides are 5 to 7 times higher in the bottom-stratum levels below the chemocline.
- uranium in the sediment is 2 to 3 orders of magnitude greater than lake bottoms in the area while radium is 2 times greater.
- water quality in the upper levels is satisfactory.
- fish caught in the open pit contain radionuclide levels of 1 to 2 orders of magnitude greater than background.
- there is no surface seepage out of the open-pit.
- the waste rock piles are contributing contaminated seepage to Lake Athabasca.

Areas of investigation that could be considered for the Gunnar area include:

- surface stabilization characteristics of the tailings with respect to vegetation for dust and erosion control.
- monitoring of the tailings area, the open-pit and the waste rock piles with respect to surface and ground-water hydrology.
- radionuclide pathway analysis to determine the need for control structures for tailings and waste rock.
- a study of the stability of the open-pit as a long-term containment mechanism. This would include the effectiveness of the chemocline in containing the radionuclides to the lower strata.

2.3.3 Port Radium

The Port Radium site, mined for uranium by Eldorado Nuclear Limited, is located in the N.W.T. on the shores of Great Bear Lake approximately 400 km northwest of Yellowknife.

In the early years of operation radium and silver were recovered by gravity concentration and the tailings were discharged to the Cobalt Channel in Great Bear Lake.

Uranium recovery by acid leaching was initiated in 1942 and as part of this operation tailings in the Cobalt Channel were reprocessed for uranium recovery and subsequently discharged into small lakes on the peninsula and into Murphy Bay.

From 1964 to 1982 Echo Bay Mines Limited operated a silver mill in Port Radium using some of the existing facilities on site.

Some of the site conditions of uranium tailings in the area (Kalin, 1982) include:

- Murphy Lake; old tailings area nearly all covered with mixture of waste rock and overburden.

- Murphy Creek; weathered uranium tailings mixed with silver tailings in small puddles and depressions.
- Murphy Bay; lake sediments and tailings likely well mixed.
- Radium Lake; old uranium tailings completely covered with waste rock and overburden.
- Cobalt Channel; tailings on bottom of channel.
- West Adit; waste rock slope with uranium tailings at a pH of 3.0 to 3.5 and small tailings area at pH 4.0 to 4.5.

The close-out plans of Echo Bay Mines Limited was to include the covering of all surface tailings sites thereby leaving no exposed tailings at Port Radium.

Due to the presence of some tailings at the bottom of Great Bear Lake in Cobalt Channel and Murphy Bay and due to the acidic nature of the uranium tailings that have been identified further investigations are likely warranted for this area. This will provide an assessment of any potential environmental effects from these wastes.

2.3.4 Rayrock

The Rayrock tailings site is located approximately 150 km N.W. of Yellowknife in the N.W.T. The mill was operated from 1957 to 1959 by Rayrock Mines Ltd. The operation generated approximately 80,000 tonnes of tailings which were deposited in two separate areas, a small wet swampy area adjacent to Sherman Lake, separated by a roadway of waste rock, and a smaller area approximately 500 m away near a small lake. The two areas of tailings are in separate drainage systems.

Although some environmental sampling has been carried out in the area, results were inconclusive and a survey of existing

environmental conditions at this site would seem warranted.

2.3.5 Bicroft

The Bicroft tailings sites, located near Bancroft, Ontario are made up of three tailings area; Auger Lake, Bicroft Proper, and the Bicroft Swamp(Figure 9).

The mill, operated by Bicroft Uranium Mines Ltd., used an acid leach process and discharged approximately 2,000,000 tonnes of neutralized tailings from 1958 to 1963.

The surface conditions of the sites were surveyed by Kalin (1982) and the surface characteristics of the 3 sites are described in Figures 10, 11 and 12.

Some general comments on the site conditions at Bicroft include:

- the Auger Lake and Bicroft Proper areas have revegetated with indigenous vegetation.
- beaver activity results in flooding of the Bicroft Swamp area but some revegetation has taken place.
- pH of water on the tailings surface is in the range of 6 to 7 .
- water quality on the tailings surface is poor but the water quality in adjacent creeks and lakes is good.

The surface water quality in the immediate area is acceptable probably because of the dilution effect of water flows in the vicinity. Some investigations into groundwater quality and radionuclide migration may be warranted for this area.

Based on natural ecological processes that are currently active in this area the development of extensive wetland communities may provide a natural reclamation method which

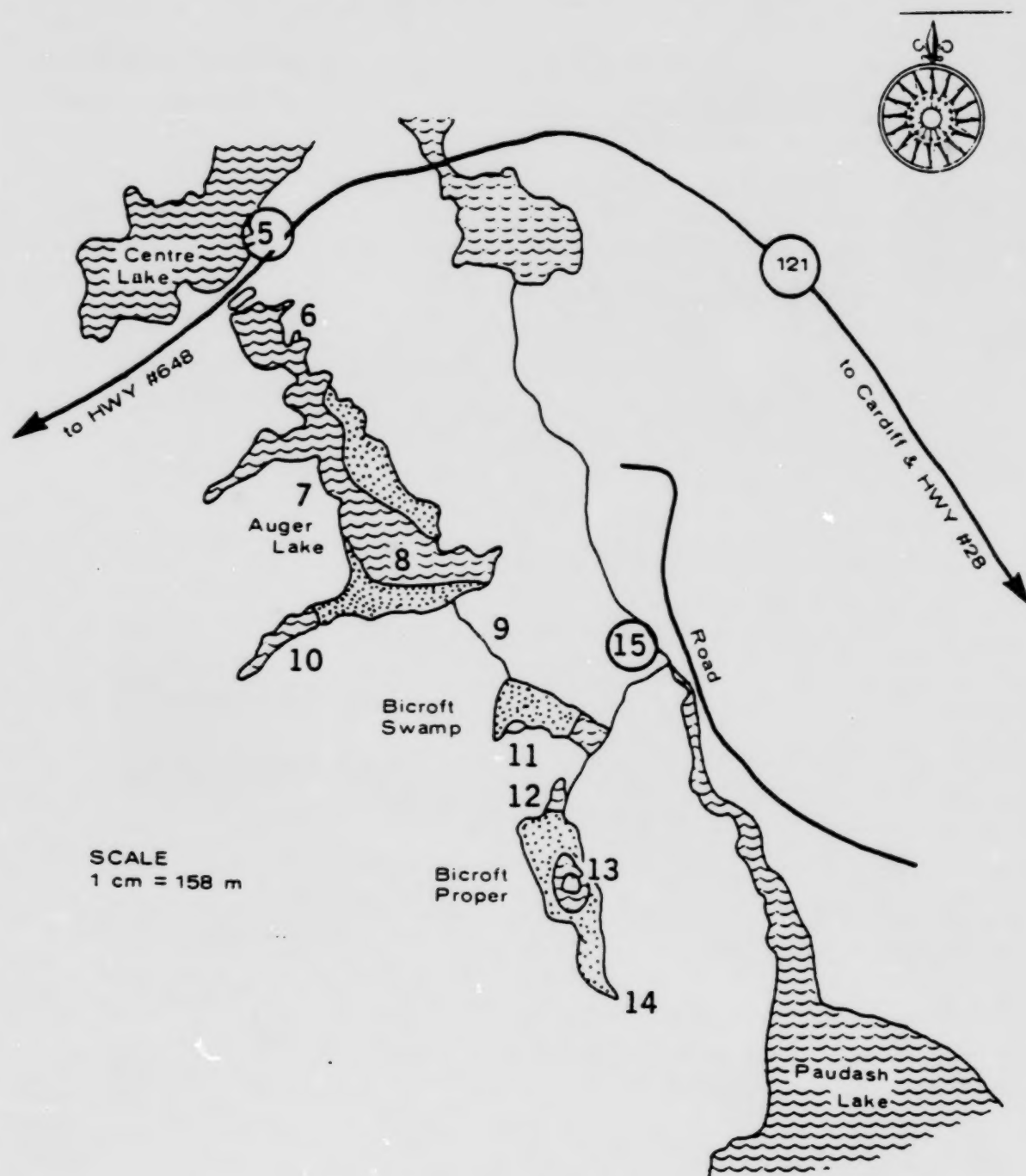


Figure 9 - Bicroft Tailings Sites
(from Kalin 1983)

Scale: 1 cm = 22.2 m

Area: 0.018 km²

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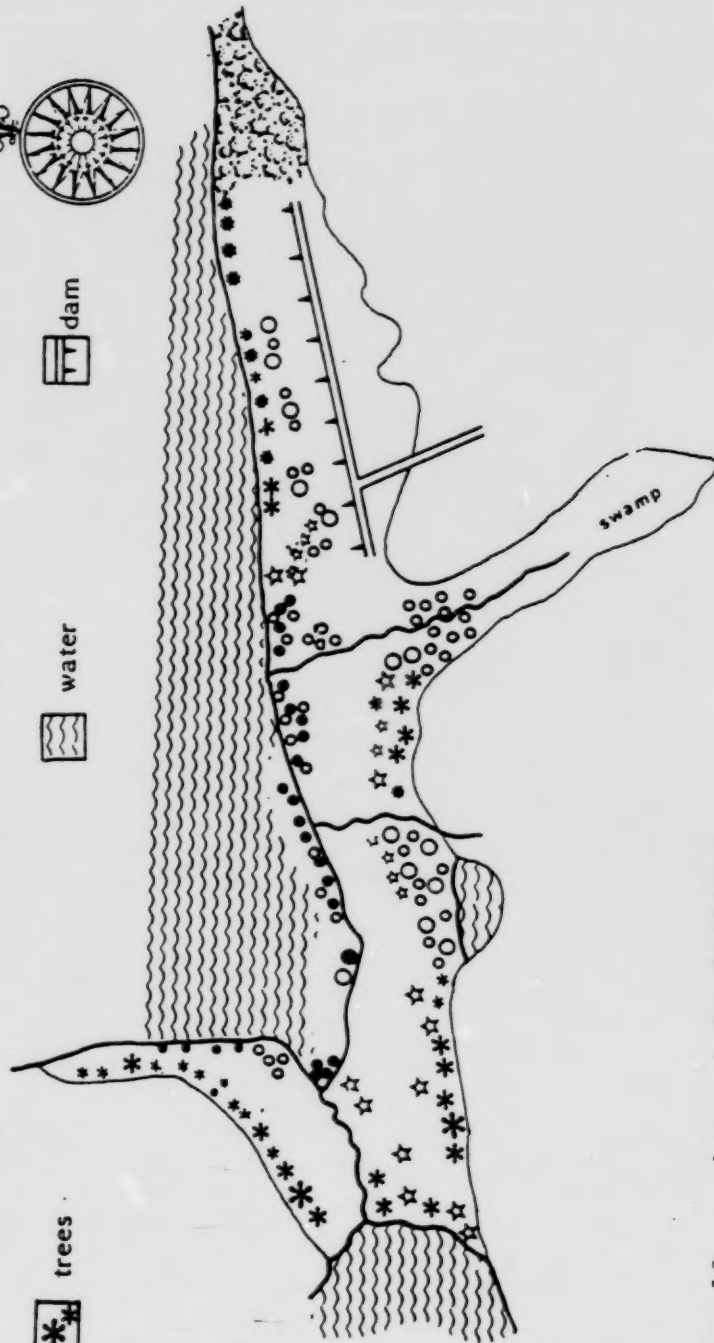
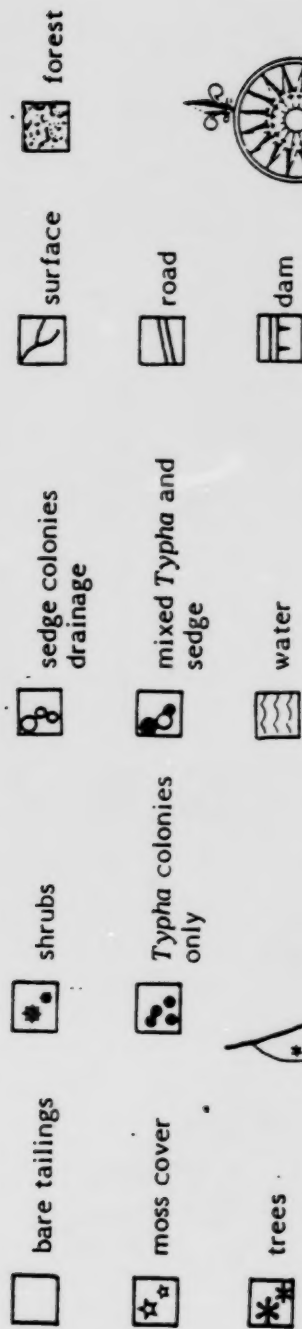


Figure 10 - Auger Lake Tailings
(from Kalin, 1983)

Scale: 1 cm = 24.1 m
 Area: 0.038 km²

LEGEND

-  bare tailings
-  moss cover
-  trees
-  shrubs
-  *Typha* colonies only
-  sedge colonies only
-  mixed *Typha* and sedge
-  water
-  surface drainage
-  pipeline
-  dam

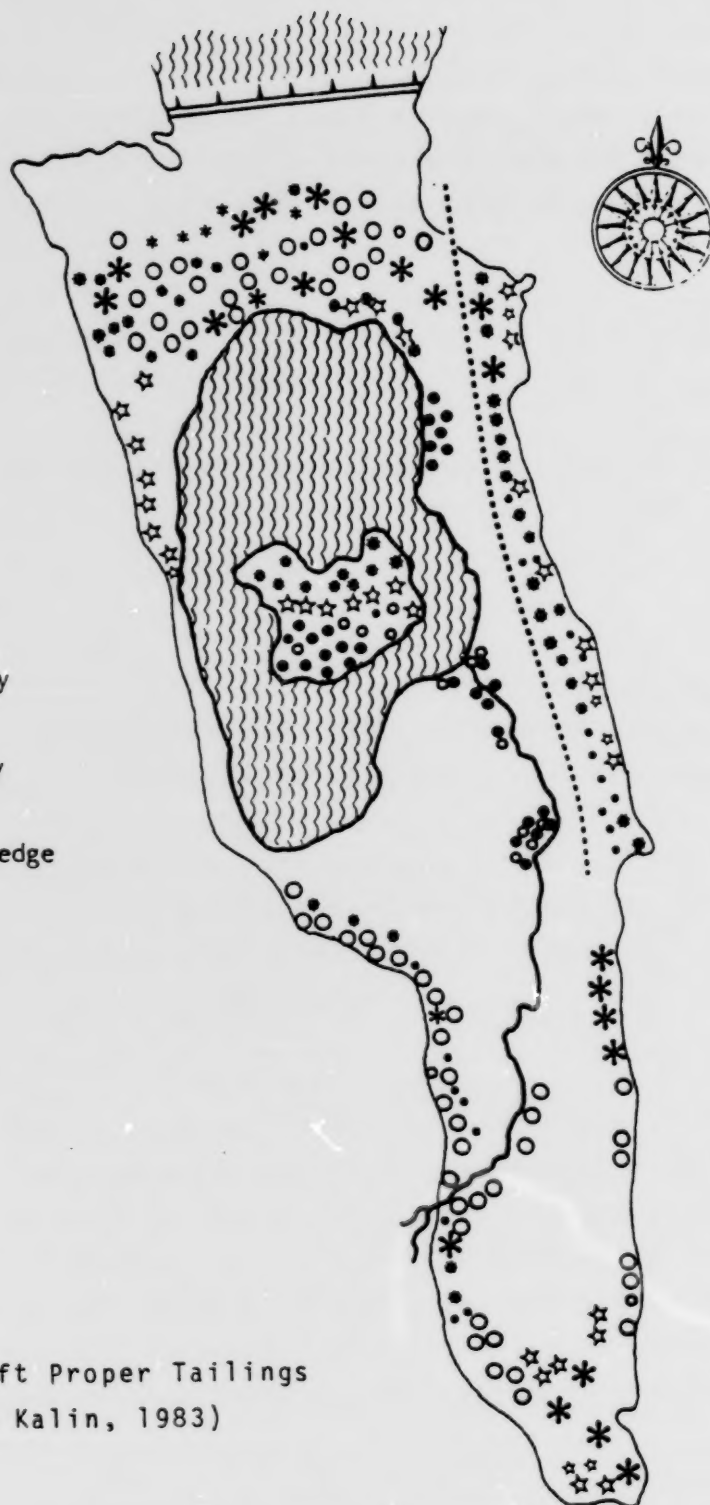


Figure 11 - Bicroft Proper Tailings
 (from Kalin, 1983)

Scale: 1 cm = 13.3 m

Area: 0.065 km²

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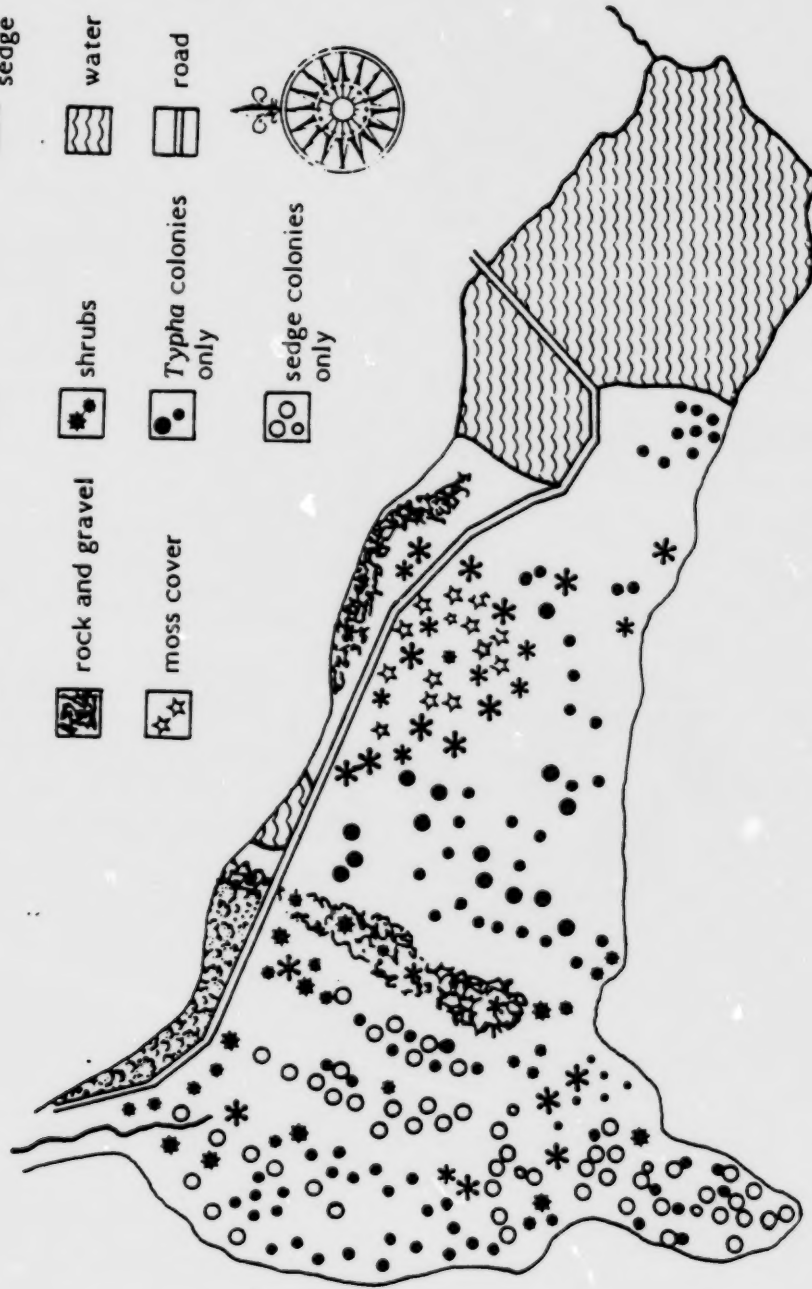
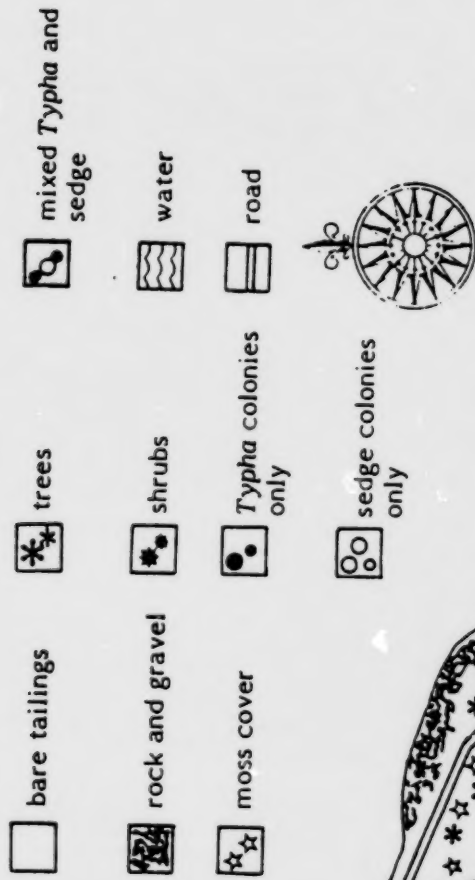


Figure 12 - Bicroft Swamp Tailings
(from Kalin, 1983)

is site-specific for the Bicroft and Dyno areas. This would seem to warrant further investigations.

2.3.6 Dyno

The Dyno mill was operated by Canadian Dyno Mines Ltd. from 1958 to 1960 with approximately 360,000 tonnes of tailings discharged to Farrell Lake with a rock dam separating the tailings from the lake.

The surface characteristics of the tailings site have been described by Kalin, 1982 (Figure 13).

The comments for the Bicroft area generally apply to the Dyno tailings.

2.3.7 Faraday

The Faraday Mine was operated by Faraday Uranium Mines Ltd. from 1957 to 1964. A total of 1,800,000 tonnes of tailings were deposited in a swampy area near Bentley Lake (Figure 5).

These tailings, also known as Madawaska Tailings Pond No.2, were covered with overburden, seeded and fertilized to provide a good cover of indigenous vegetation.

2.3.8 Nordic

The Nordic mine, located approximately 6 km south of Elliot Lake, Ontario, was operated by Rio Algom Limited from 1957 to 1968. Approximately 11,000,000 tonnes of neutralized tailings were discharged to the tailings area which is contained by rockfill dams on three sides and a hill on the north side. The mill circuit consisted of acid leaching, ion exchange and ammonia precipitation which is the typical

Scale: 1 cm = 39.1 m
Area: 0.027 km²

LEGEND

-  bare tailings
-  moss cover
-  trees
-  shrubs
-  sedge colonies only
-  water
-  surface drainage
-  dam

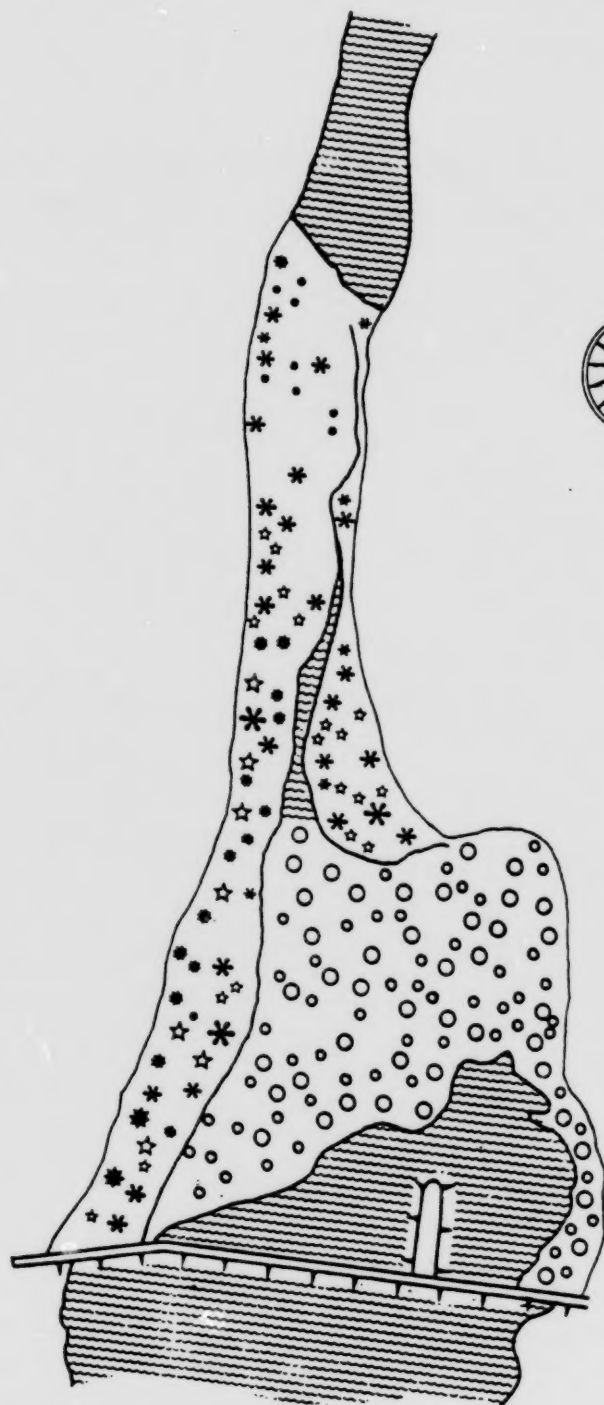


Figure 13 - Dyno Tailings Site
(from Kalin, 1983)

uranium circuit operated in the Elliot Lake area.

The complete tailings area was revegated by Rio Algom Limited during the period 1971 to 1978. The present surface characteristics of the Nordic Main and the Nordic West Arm tailings are shown in Figure 14 and 15. The complete area is well revegated with trees naturally encroaching on the surface. Wind erosion problems have virtually been eliminated.

The acidic seepage and runoff from the Nordic tailings is collected and treated with lime and BaCl_2 for neutralization and radium removal. North Nordic Lake is used as a settling pond for the waste sludge.

Due to the accessibility of this tailings area numerous investigations have been carried out at this site. Vegetation studies have been carried out by Murray (CANMET) and ground-water investigations have been done by Cherry (1982).

Some of the major comments for this area include:

- the tailings are pyritic (5-6% FeS_2) and acid generating
- primary concern is the acidic seepage with its inherent heavy metals content and radionuclides.
- the front zone of low pH seepage water moves at a slower rate than the groundwater front due to neutralization effects of calcite in the sand aquifer.
- in front of the low pH zone the concentrations of heavy metals and radionuclides are acceptable.
- behind this front the pH is low and high concentrations of heavy metals and radionuclides exist.
- lowering of the water table to assist in revegetation of slimes area resulted in an increase in depth of pyrite oxidation and acid generation.
- precipitation and adsorption reactions in the pH control zone plays an important part in the control of contaminants in the groundwater.

Scale: 1 cm = 93.2 m

Area: 0.85 km²

LEGEND

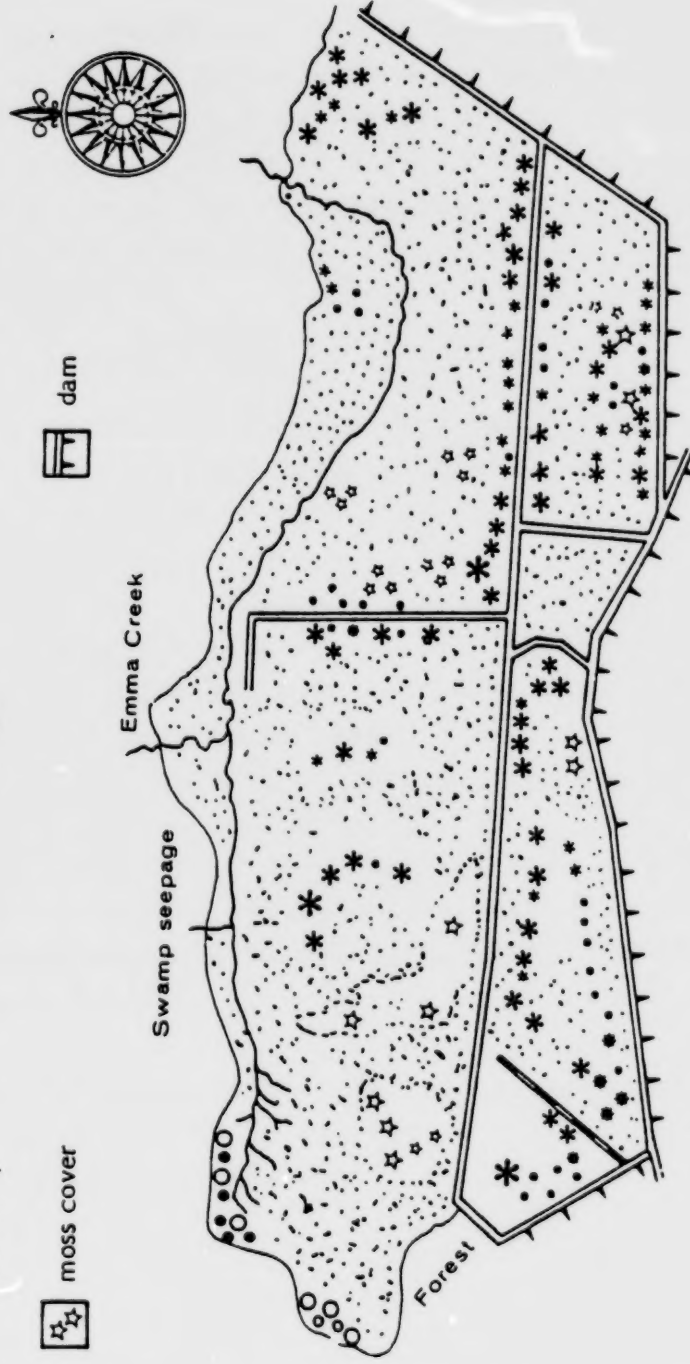
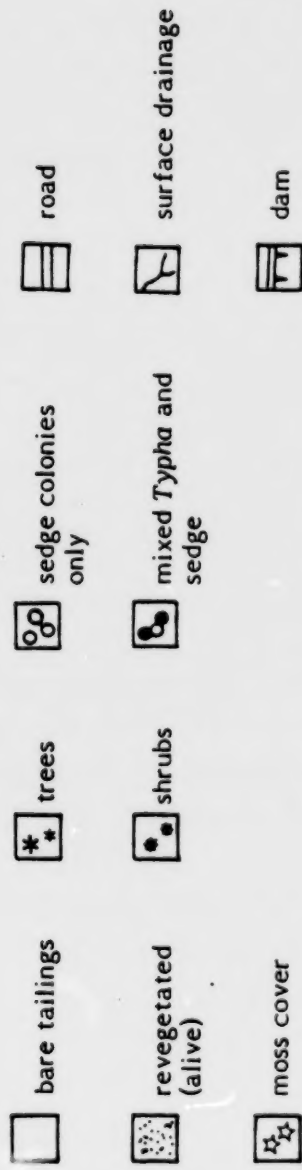


Figure 14 - Nordic Main Tailings
(from Kalin, 1983)

Scale: 1 cm = 55.1 m

Area: 0.16 km²

LEGEND

	bare tailings		trees		rock and gravel
	revegetated (alive)		tree seedlings		water
	revegetated (dead)		shrubs		road
	moss cover		<i>Typha</i> colonies only		surface drainage
			sedge colonies only		dam
			mixed <i>Typha</i> and sedge		forest

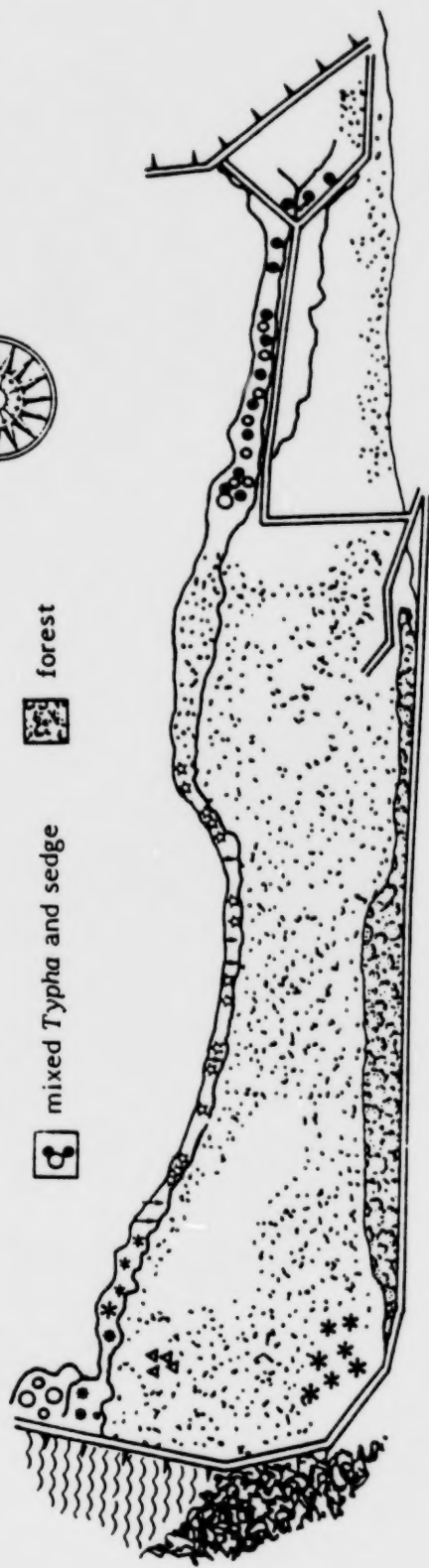


Figure 15 - Nordic West Arm Tailings
(from Kalin, 1983)

- the vegetated cover does not seem to reduce the rate of pyrite oxidation in the shallow zone or reduce the net downward movement of input water.

Although continual monitoring of this tailings area may be warranted in the long term further investigations are required in order to minimize or stop pyrite oxidation in the top zone of tailings and to minimize water input into the tailings mass. The mechanism of radionuclide migration will also need further investigations.

2.3.9 Lacnor

The Lacnor mine, located 6 km from the town of Elliot Lake, was operated by Northspan Uranium Mines Limited from 1957 to 1960. A total of approximately 2,700,000 tonnes of tailings were neutralized and dumped into a small lake.

The surface characteristics were assessed by Kalin, 1982 (Figure 16). The tailings are well covered with introduced vegetation but some bare spots remain due to surface drainage problems. A portion of the tailings are underwater.

The seepage and runoff from this tailings area is directed, by gravity, to the Nordic tailings area and the contaminated water is combined with the Nordic seepage and treated in the Nordic treatment facility.

Long-term remedial measures that may be proposed for Nordic tailings will also need to be applied to the Lacnor tailings area since Lacnor seepage and runoff reports by gravity to the Nordic site.

2.3.10 Stanrock

The Stanrock operation was operated by Stanrock Uranium

Scale: 1 cm = 73.1 m

Area: 0.24 km²

LEGEND

	bare tailings		water
	revegetated (alive)		road
	<i>Typha</i> colonies only		surface drainage
	mixed <i>Typha</i> and sedge		dam
	rock and gravel		

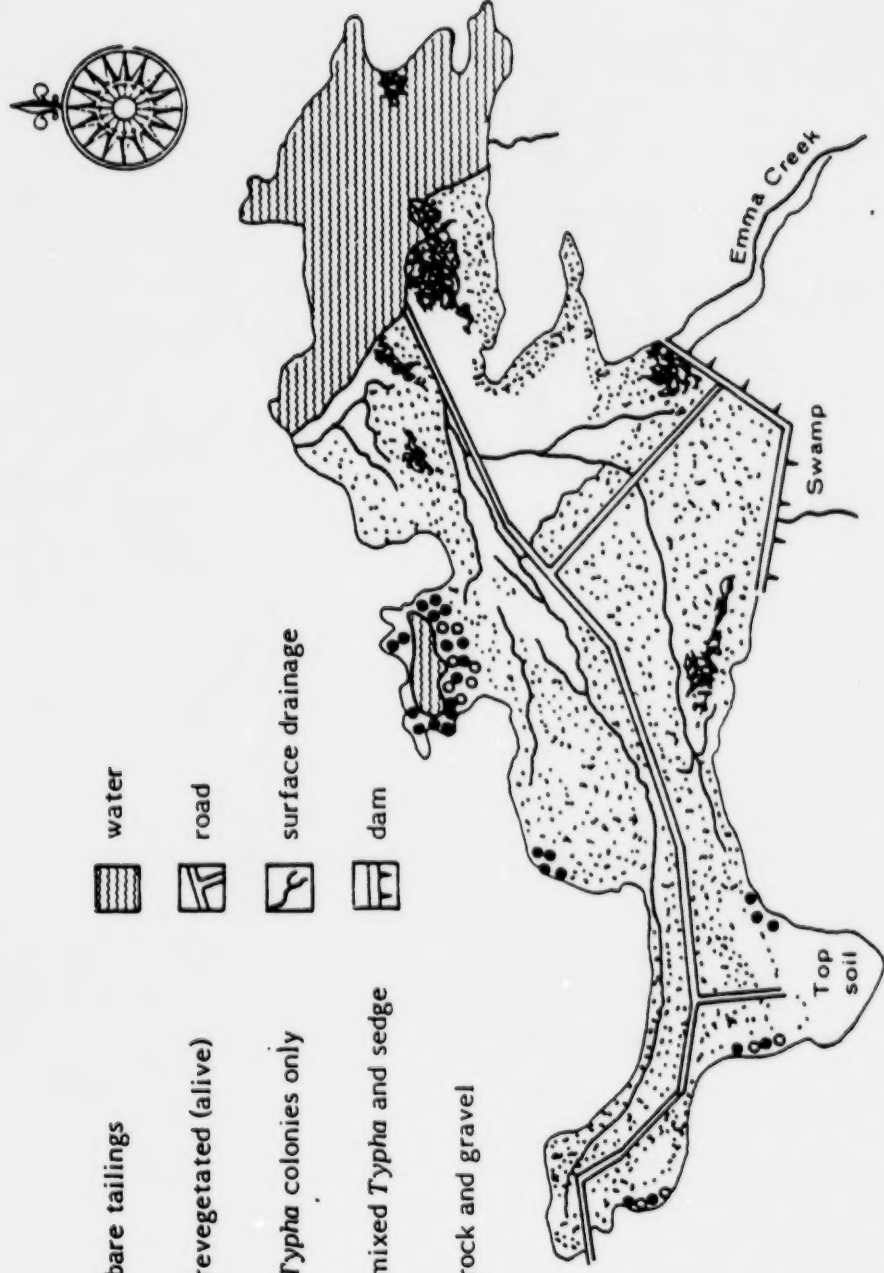


Figure 16 - Lacnor Tailings Site
(from Kalin, 1983)

Mines Ltd. from 1958 to 1964 with approximately 5,800,000 tonnes of neutralized tailings being discharged to the tailings site.

An additional 2,200,000 tonnes of tailings were discharged to the Stanrock tailings site from the adjacent Can-Met mill operated by Can-Met Exploration Ltd. from 1957 to 1960.

The Stanrock operation continued to recover uranium with a bacterial leach operation from 1964 to 1969.

The tailings site is located north of Elliot Lake, approximately 12 km east of Highway 108. A dam failure on the east side of the tailings area has caused tailings to spread into an adjacent swampy area and creek (Figure 6). This dam is constructed of classified tailings sands.

The Stanrock main area was sprayed with lime in 1978 as a method of dust control. This has accelerated the encroachment of vegetation onto the tailings area.

The surface characteristics of the Stanrock Main, the Stanrock Dam A and Stanrock Dam G area have been detailed by Kalin, 1982 (Figure 17, 18, 19).

Seepage and runoff from the tailings site is collected and treated with lime and BaCl_2 . Neutralized minewater from the re-activated mining operation is discharged at present to the tailings area. Stanrock ore is trucked to the Denison mill for processing.

The nature of this tailings area is such that in-depth monitoring may be warranted to determine the potential environmental problems that exist at this site. The effect of the tailings wash-out downstream from the dam should be assessed in order to recommend remedial measures that may be necessary.

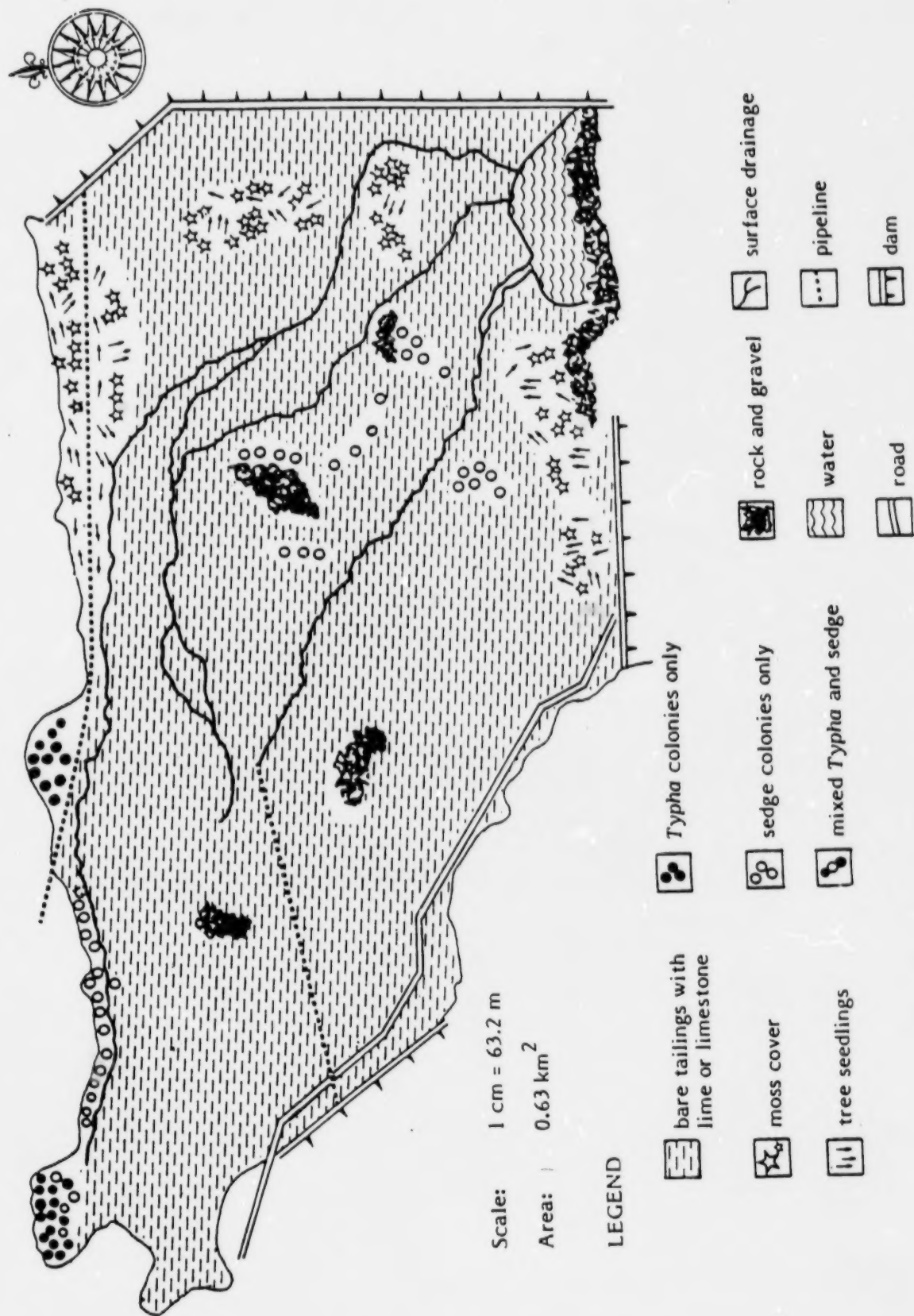


Figure 17 - Stanrock Main Tailings Site
(from Kalin, 1983)

Scale: 1 cm = 42.4 m

Area: 0.06 km²

LEGEND

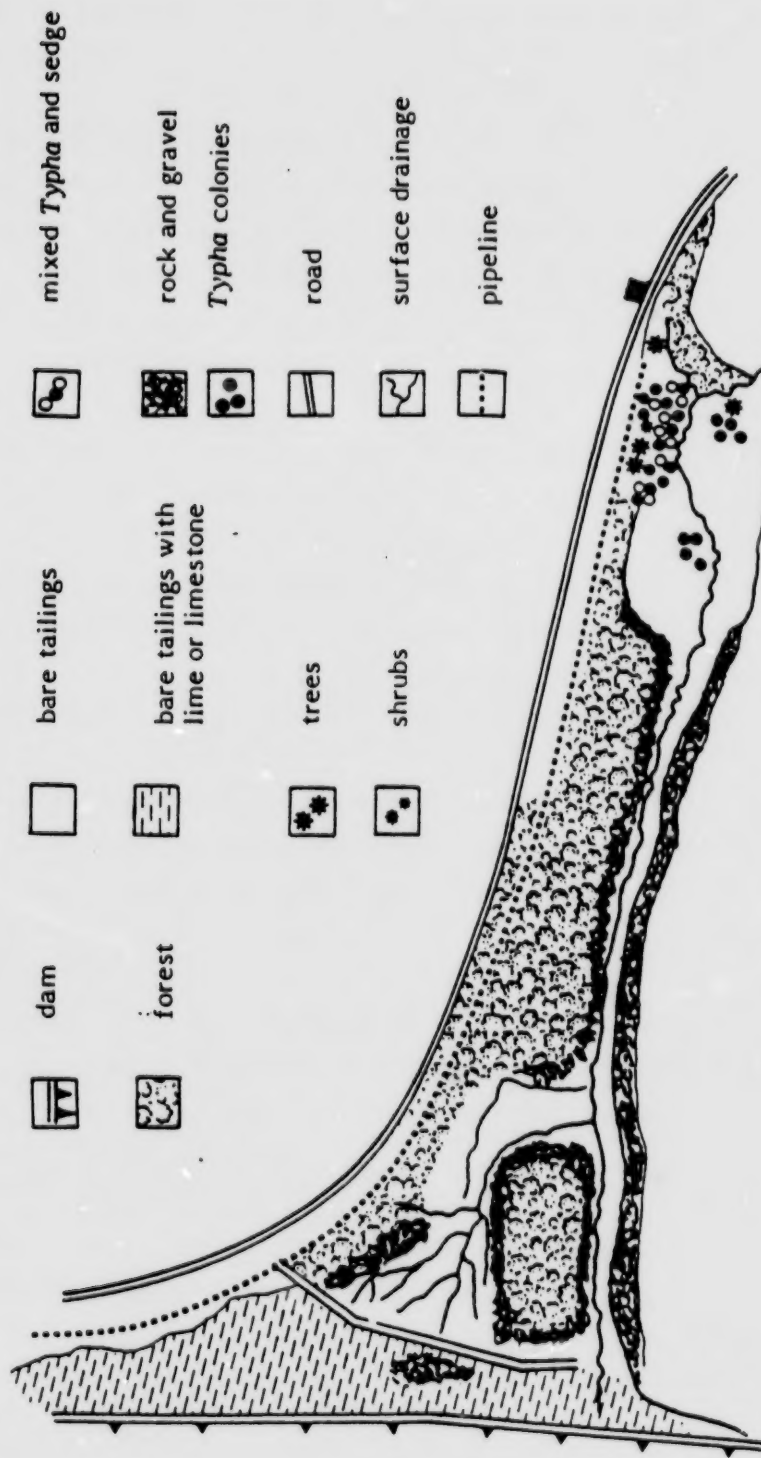


Figure 18 - Stanrock - Dam A Tailings
(from Kalin, 1983)

Scale: 1 cm = 41.2 m

Area: 0.02 km²

LEGEND

	bare tailings		rock and gravel
	<i>Typha</i> colonies only		water
	sedge colonies only		dam
	mixed <i>Typha</i> and sedge		

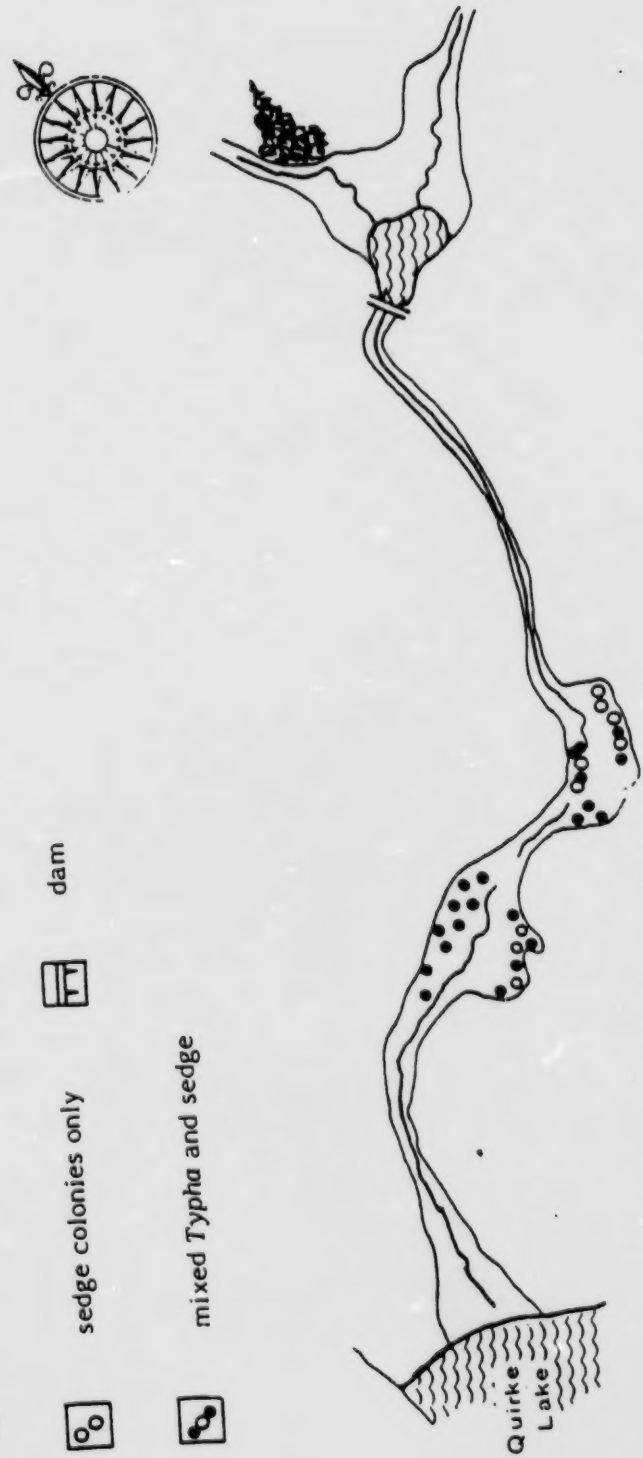


Figure 19 - Stanrock - Dam G Tailings
(from Kalin, 1983)

2.3.11 Spanish American (Olive Lake)

The Spanish American mill was operated for a brief period by the Northspan group in 1958-1959. A total of 450,000 tonnes of neutralized tailings were discharged to Olive Lake.

The surface characteristics of this tailings area (Kalin, 1982) are described in Figure 20. The majority of the surface tailings are revegetated and some of the tailings are underwater. The seepage from this area flows by gravity to the Long Lake tailings area where it is treated with the Denison tailings seepage and runoff.

The features of this tailings area would lend itself quite well to a field investigation of the water cover close-out alternative for pyritic tailings. Minimal work would be required to place the existing tailings underwater and the site characteristics are such that it could be easily monitored.

2.3.12 Pronto

The Pronto mine, located near Spragge, Ont. on Highway 17, was operated by Pronto Uranium Mines Ltd. from 1955 to 1960. A total of 2,100,000 tonnes of tailings were discharged to the tailings site.

The uranium tailings have been partially revegetated but copper tailings, from a period of copper concentrate production at this mine, are not revegetated due to their compaction and slimes content.

Surface runoff (pH 3) is treated with BaCl_2 followed by lime neutralization to pH 8-9.

Scale: 1 cm = 48.7 m
 Total area: 0.14 km²
 East tailings: 0.03 km²
 Northwest tailings: 0.02 km²

LEGEND

	bare tailings		<i>Typha</i> colonies only		rock and gravel
	revegetated (alive)		sedge colonies only		water
	shrubs		mixed <i>Typha</i> and sedge		road

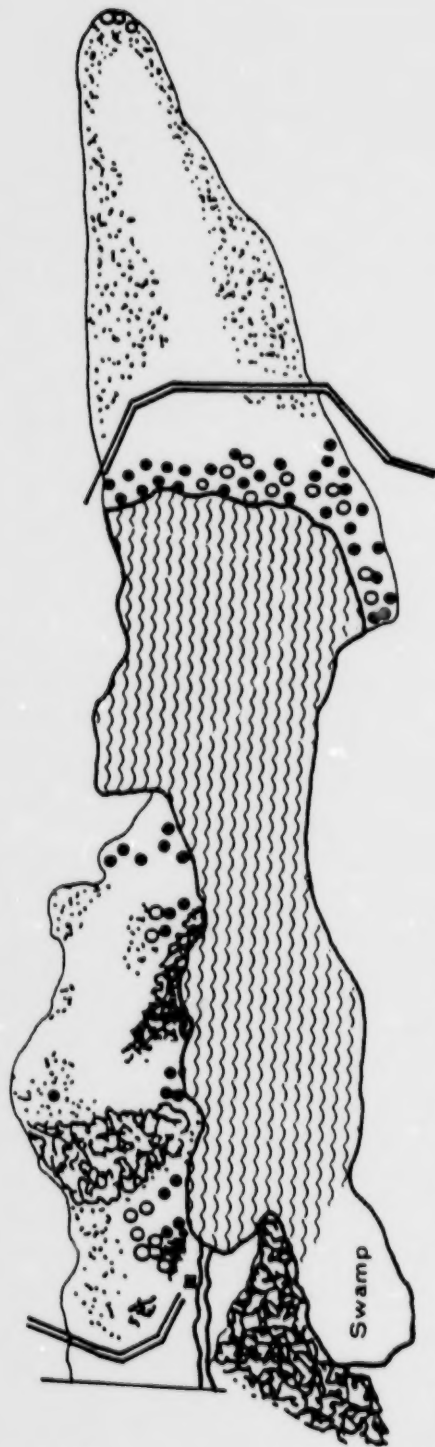


Figure 20 - Olive Lake Tailings
 (from Kalin, 1983)

For a short period kiln rejects and dust from the nearby Reiss Lime operation were disposed in this tailings area but this scheme did not prove to be practical.

Monitoring investigations in this tailings area may be warranted due to its proximity to Lake Huron.

2.4 Close-out Tailings

At present there are 3 operations that are currently in a close-out situation. They include Eldorado Nuclear Limited in Beaverlodge, Sask., Madawaska Mine in Bancroft, Ont. and the Agnew Lake Mine near Espanola, Ont.

2.4.1 Beaverlodge

The Beaverlodge operation of Eldorado Nuclear Limited, located on the shore of Beaverlodge Lake in northern Saskatchewan, was shut down in June 1982 after 30 years of operation. The mill feed originated from the Fay/Verna Mine, the Dubyna Mine as well as many satellite mines in the area. A location map is shown in Figure 21. The mill circuit used a carbonate leaching circuit and caustic precipitation. The tailings from this operation are alkaline and are not acid generating.

Mine backfill was practiced in this operation with approximately 3,500,000 tonnes of tailings used for this purpose. The remaining tailings, approximately 6,000,000 tonnes, were deposited in nearby lakes.

The tailings decant water and minewater is treated with barium chloride, followed by settling in settling ponds prior to discharge to Beaverlodge Lake.

The tailings and waste areas to be closed-out in the Beaverlodge Area include:

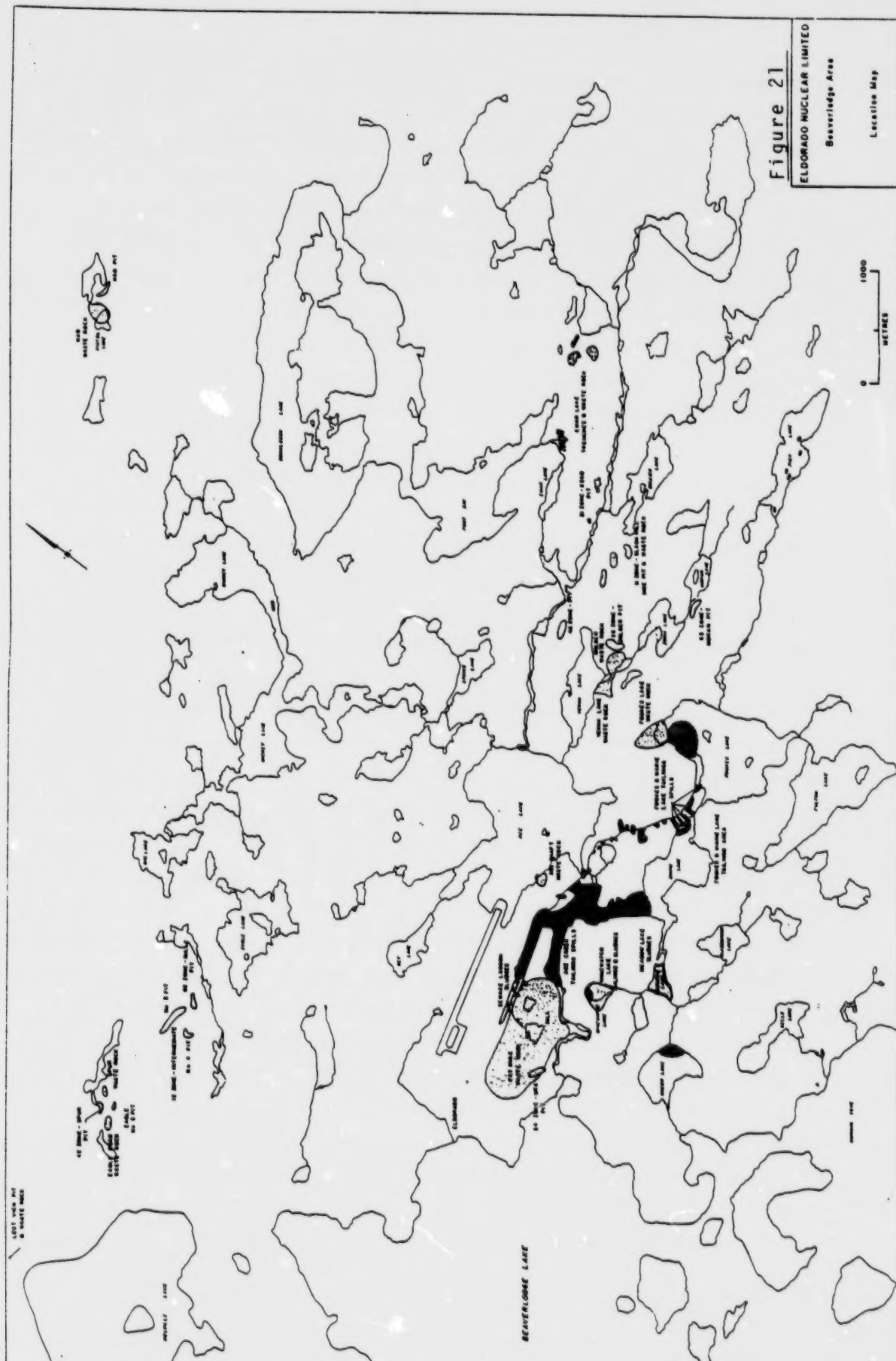


Figure 21

ELDORADO NUCLEAR LIMITED

Beveridge Area

Executive Manager

(from ENL Report, June 1982)

- Fookes and Marie Lake tailings area where tailings are in the lake and as beaches on the shoreline.
- Fookes and Marie Lake tailings spills which includes all spills within the watershed boundaries of the two lakes.
- Ace Creek tailings spills within the Ace Creek watershed downstream of Ace Lake as well as tailings in the old backfill preparation area.
- Meadow Lake treatment plant sludges and tailings within the Meadow Lake sub-watershed.
- Minewater Lake tailings and sludges which includes mine-water treatment sludges and precipitates as well as some tailings from the early years of operation.
- Waste rock stockpile areas in the vicinity of the mining operations.

Water cover of tailings areas is the present conceptual close-out plan for this area but other site-specific options are currently being evaluated. The reclamation activities to be undertaken at Beaverlodge will provide actual field experience for potential reclamation options. This information should prove valuable to the N.U.T.P.

The enormous task of satisfactorily closing-out the Beaverlodge mining area underlines the important point that future operations will need to pay close attention to site selection and tailings disposal techniques with the long-term objective of reclamation in mind.

2.4.2 Madawaska

The Madawaska operation near Bancroft, Ontario is presently on a care-and-maintenance basis with the tailings area being reclaimed with a rip-rap cover of waste rock and gravel.

This operation was re-activated by Madawaska Mines Ltd. in 1977 and operated until June 1982 using an acid-leach circuit, ion exchange and magnesium precipitation. A total of approximately 2,000,000 tonnes of neutralized tailings were deposited to the tailings site east of the mill during this period. Approximately half of the tailings decant water was re-used in the mill and the remainder was treated with BaCl_2 and discharged via a settling pond and gravel bed. The area is described in Figure 22.

Site specific comments for this tailings area are:

- the gravel bed for effluent clarification is acting as a radium sink.
- the tailings are not acid-generating and thus contaminant migration problems should be minimal.
- the base beneath the tailings area has good cation exchange capacity which will ensure the capture of any contaminant that may be contained in the seepage.
- the grout curtain that was installed led to a reduction in seepage flow through the east dam but it was not entirely cut off and some seepage occurs into Bentley Lake. However, the cation adsorption capacity in the area reduces the radium to acceptable levels.

The presence of monitoring wells in this tailings area will allow data to be generated for a contoured, rip-rap cover reclamation plan for non-acid generating tailings where the tailings is underlain with a soil of good cation adsorption quality. This site-specific information will enhance the general knowledge of this reclamation option and should prove useful to the N.U.T.P.

2.4.3 Agnew Lake

The Agnew Lake mine, located near Espanola, Ontario, is operated by Agnew Lake Mines Ltd. using underground leaching and

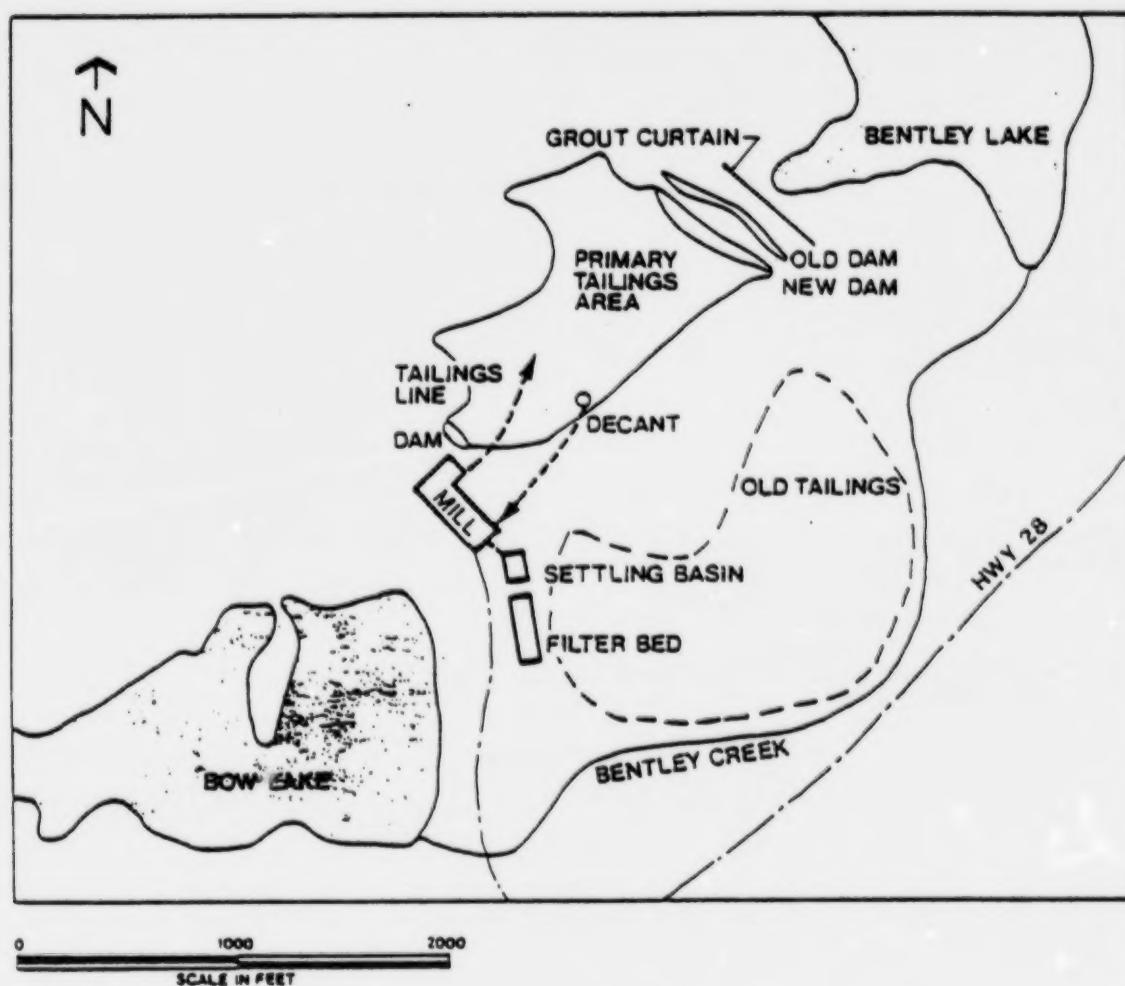


Figure 22

URANIUM TAILINGS MANAGEMENT SYSTEM
BANCROFT, ONTARIO: MADAWASKA MINES

(from Kilborn, Beak, 1979)

heap leaching with ion exchange/solvent extraction and ammonia precipitation. This operation which started up in 1977, is due to close in 1983 and reclamation procedures have already been initiated.

The tailings from this operation consist of precipitate wastes resulting from the neutralization and treatment of waste solutions from the plant. The wastes are discharged to a valley which is isolated by an impervious, hypalon-lined dam on one side and an earth-wall dam with a control tower at the other end. Seasonal discharge of effluent to a polishing pond and then to the water course is practiced (Figure 23).

Approximately $400,000 \text{ m}^3$ of precipitate wastes, made up of gypsum, iron hydroxides, thorium hydroxides and radium sulphates, are contained in this area. This material is normally 12% solids and has a permeability of 10^{-5} cm/sec .

The other waste material from this operation includes approximately 2 million tonnes of leached ore on surface.

The close-out plan currently being carried out includes the transfer of the leached ore to the sludge pond which will reduce the acid-generating potential of the ore while allowing the sludge pond to be solidified and revegetated. Vegetation tests have shown that a sand cover over the waste area would be sufficient to provide the necessary vegetation cover. The slope of the two dams will be reduced to 2:1 using waste rock.

Although this area is very site-specific with respect to tailings management the proposed 5-year monitoring program by Agnew Lake Mines Ltd. should provide pertinent information for inclusion in the N.U.T.P.

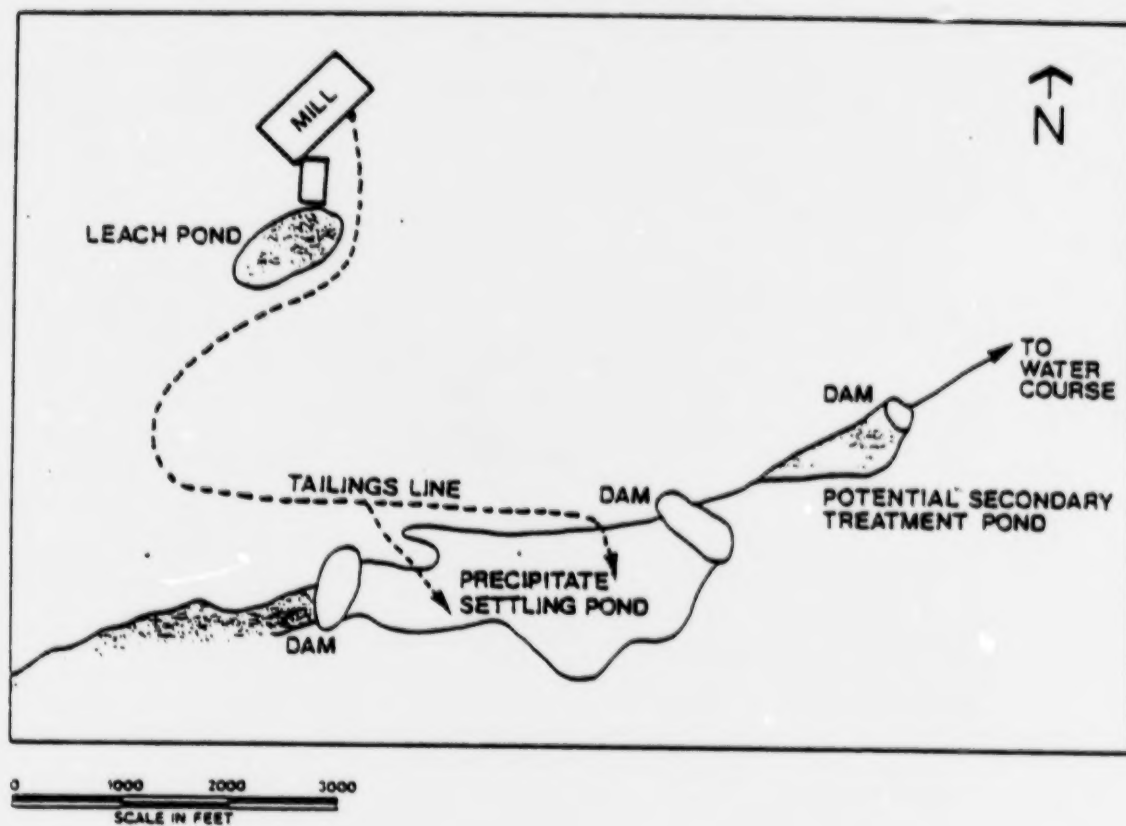


Figure 23

**URANIUM TAILINGS MANAGEMENT SYSTEM
ELLIOT LAKE, ONTARIO: AGNEW LAKE**

(from Kilborn, Beak, 1979)

2.5 Active Tailings

The presently active tailings areas in Canada include the facilities for Quirke, Panel and Denison in the Elliot Lake area (Figure 6) and the Cluff Mining and Rabbit Lake operations in northern Saskatchewan (Figure 3). The capacities of each mill are given in Table 2.

2.5.1 Quirke

The Quirke mine and mill, operated by Rio Algom Limited, was operated from 1956 to 1961 and then re-started in 1968. The mill, using acid leach, ion exchange and ammonia precipitation circuits has a capacity of 6400 t/day but is currently milling at a rate of 4500 t/day.

The neutralized tailings are discharged as a slurry to the Bud Lake tailings basin (Figure 24) which presently contains approximately 27,000,000 tonnes of tailings in an approximate area of 80 ha. This tailings area is presently being expanded to provide additional storage capacity which is required for the continuing operation.

The tailings decant water is treated with BaCl_2 in a series of three settling ponds to reduce the radium to acceptable levels prior to discharge to the Serpent River. The build-up of sludge in these ponds is a problem which is being addressed at the present time.

2.5.2 Panel

The Panel operation, operated by Rio Algom Limited, was active from 1958 to 1961 and was re-activated in 1979. The mill process includes acid leaching, ion exchange and magnesia precipitation with a capacity of 3000 t/day. Tailings from the previous operation are estimated at 3,300,000 tonnes and new

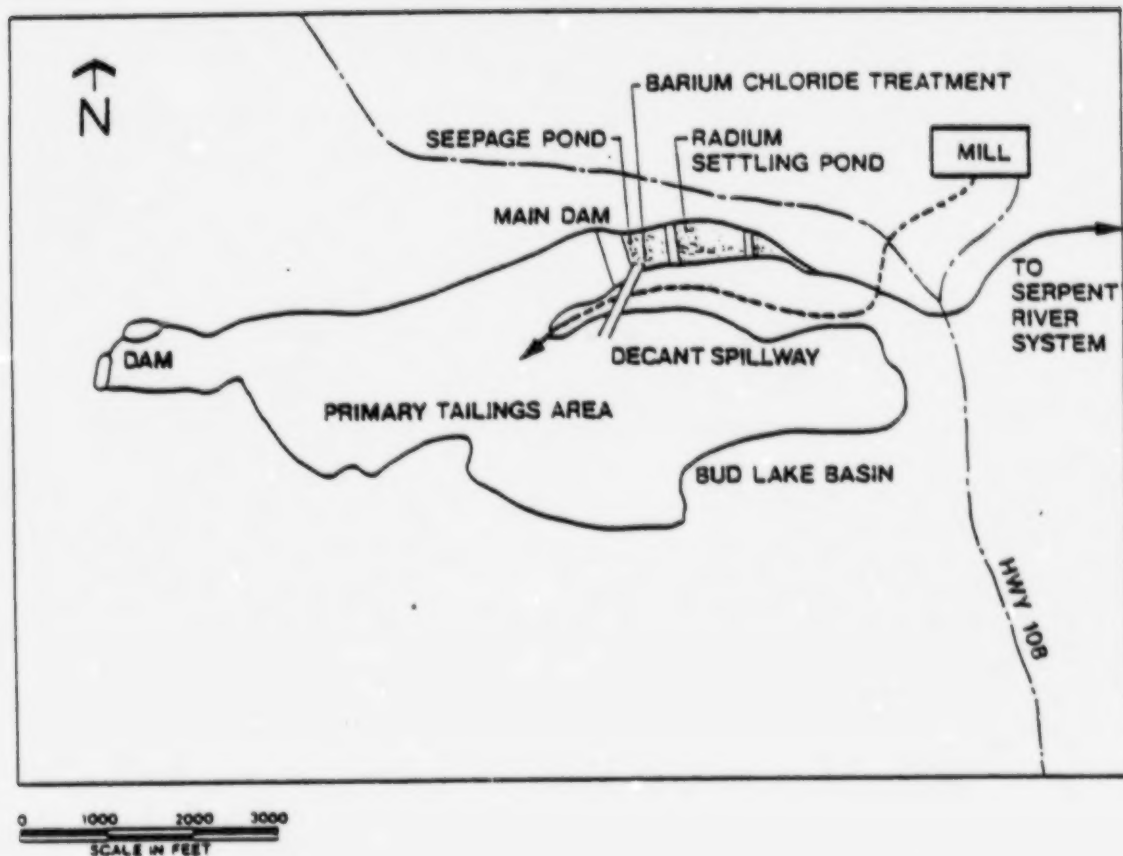


Figure 24 - Quirke Mine Tailings System

URANIUM TAILINGS MANAGEMENT SYSTEM ELLIOT LAKE, ONTARIO: RIO ALGOM

(from Kilborn, Beak, 1979)

TABLE 2OPERATING URANIUM MILLS

<u>MINE</u>	<u>CAPACITY (TONNES/DAY)</u>
Quirke	6400
Panel	3000
Denison	11000
Rabbit Lake	1800
Cluff Mining-Phase 1	*
* presently reprocessing gravity tails from Phase 1 operation	

TABLE 3.NEW URANIUM MILLS

<u>MILL</u>	<u>CAPACITY (TONNES/DAY)</u>
Key Lake	720
Stanleigh	4250
Collins Bay Project	1800
Cluff Mining-Phase 2	790

tailings deposition is approximately 3,000,000 tonnes to date.

The neutralized tailings are discharged to the Strike Lake tailings management area (Figure 25) and are deposited over a portion of the old tailings.

Tailings decant water is collected and treated with BaCl_2 and lime for radium removal and neutralization. Effluent is clarified in settling ponds prior to discharge to Quirke Lake.

Hypalon liners have been used in the construction of the perimeter tailings dams and for the baffled, settling ponds used for treated effluent clarification.

In the design of the expanded tailings area for the Panel mine reactivation a small area of old tailings located east of Dam A was left abandoned and remained in the Rochester Creek watershed. Studies had shown that this small area of tailings had no impact on the environment since the water flow in Rochester Creek is sufficiently high to mask any possible contaminant problem from these tailings. Furthermore, as most of the tailings are underwater acid generation, and hence contaminant migration, is thought not to be a problem. The surface characteristics of this area are shown in Figure 26.

Field monitoring of the Panel tailings area should provide reliable field data with respect to the efficiency of hypalon liners in tailings retaining dams as well as in settling ponds. The small area of abandoned tailings east of dam A can also provide an opportunity to assess the effect of a water cover on pyrite oxidation retardation.

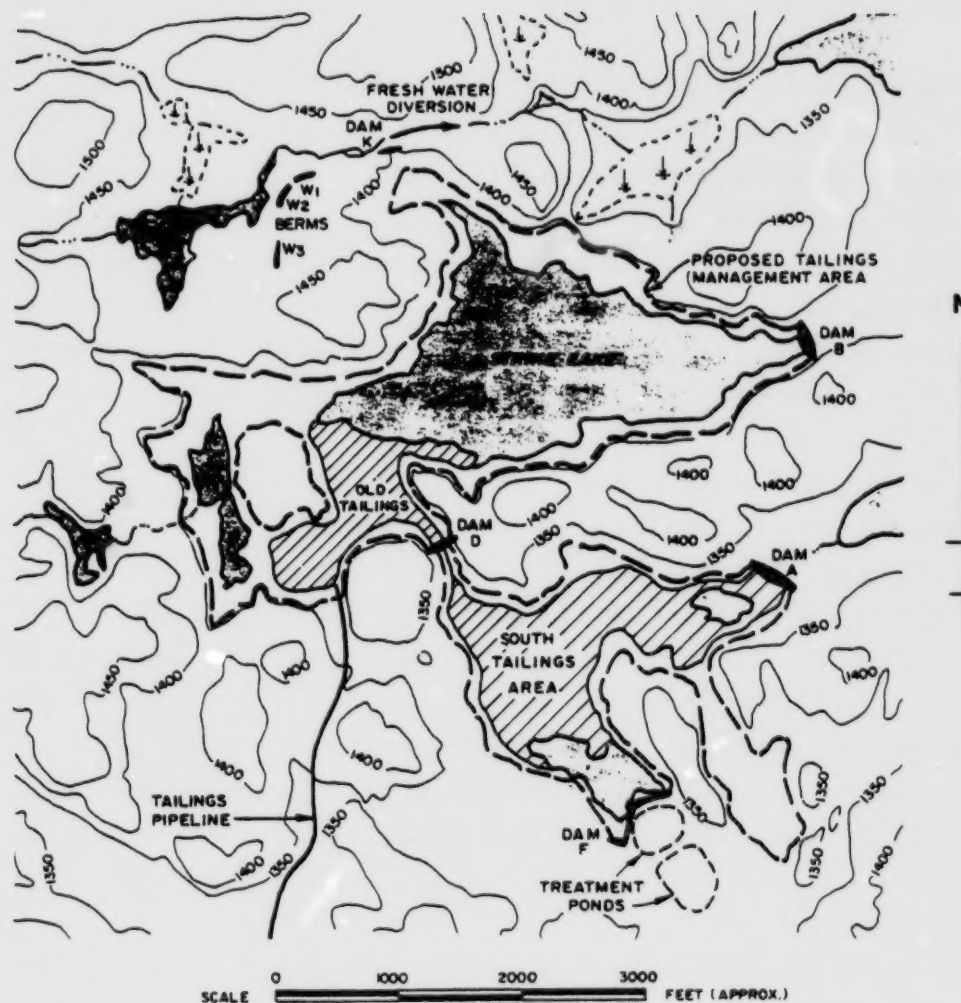
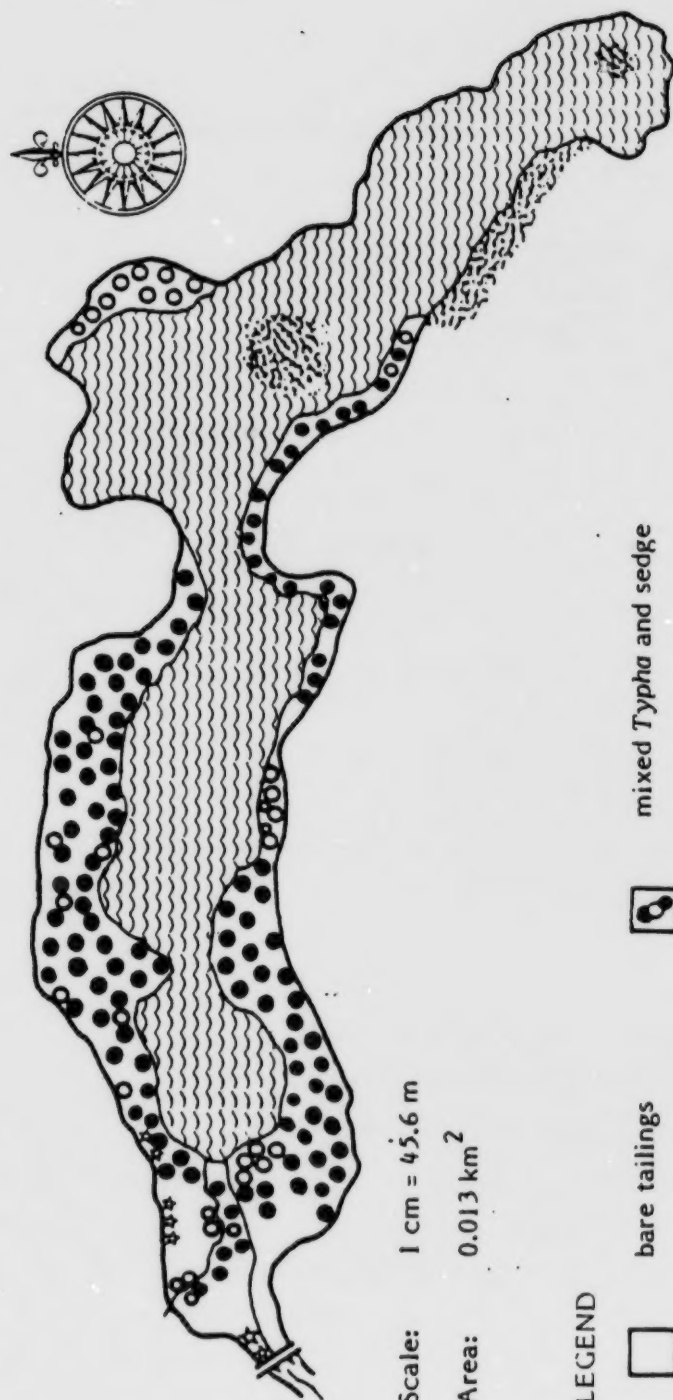


Figure 25 - PANEL TAILINGS MANAGEMENT AREA
(from Pullen, 1982)



Scale: 1 cm = 45.6 m

Area: 0.013 km²

LEGEND

	bare tailings		mixed Typha and sedge
	moss cover		rock and gravel
	Typha colonies only		water
	sedge colonies only		dam

Figure 26 -- Panel Dam A Tailings
(from Kalin, 1983)

2.5.3 Denison

The Denison mine, operated by Denison Mines Limited, has been in continuous operation since 1957. The mill throughput has been increased in stages to the present capacity of 11,000 t/day. The mill circuit is similar to the Quirke operation, that is, acid leaching, ion exchange and ammonia precipitation.

A total of approximately 40,000,000 tonnes of tailings has been deposited in the Williams Lake and Long Lake tailings basin (Figure 27). The Williams Lake area is no longer used and some reclamation work has been carried out in the lower Williams Lake tailings area using a glacial till cover and vegetation with grasses and legumes. The upper Williams Lake area contains exposed tailings. The surface characteristics of this area are described in Figure 28.

The Long Lake basin is made up of the main dam at the west end and a dam at the east end. Tailings slurry is discharged at the east end which in practice, results in the segregation of coarse and slimes with the slimes reporting to the west end of the tailings area.

Tailings decant is treated with BaCl_2 and discharged to Stollery Lake which is separated by a dyke to allow settling of the precipitated sludge before disposal to the Serpent River system.

Activities of interest at Denison with respect to the N.U.T.P. include investigations of thickened tailings for increasing the capacity of the Long Lake basin and for providing a tailings surface compatible with revegetation, as well as the practice of mine backfill as a current mining method.

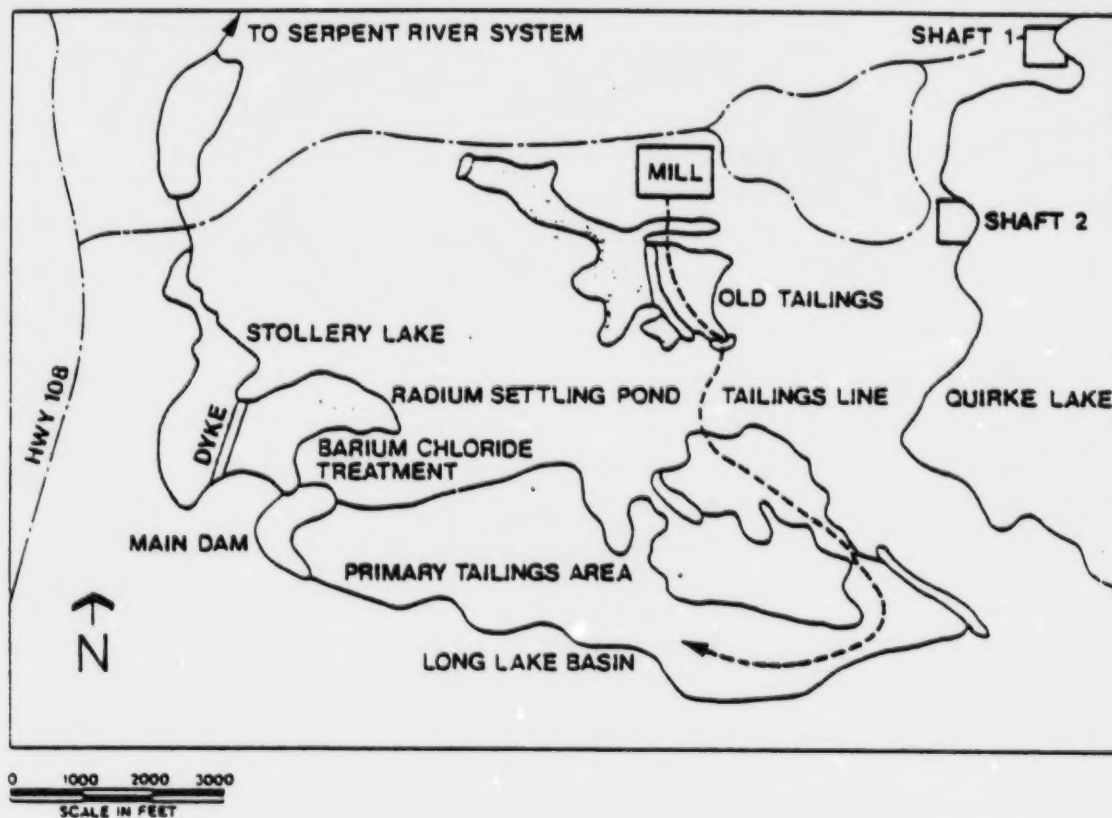


Figure 27

**URANIUM TAILINGS MANAGEMENT SYSTEM
ELLIOT LAKE, ONTARIO: DENISON MINES**

(from Kilborn, Beak, 1979)

Scale: 1 cm = 17.9 m

Area: 0.02 km²

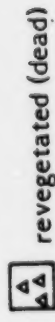
LEGEND



bare tailings



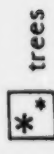
revegetated (alive)



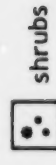
revegetated (dead)



moss cover



trees



shrubs



Typha colonies only



sedge colonies only



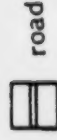
mixed *Typha* and sedge



rock and gravel



water



road

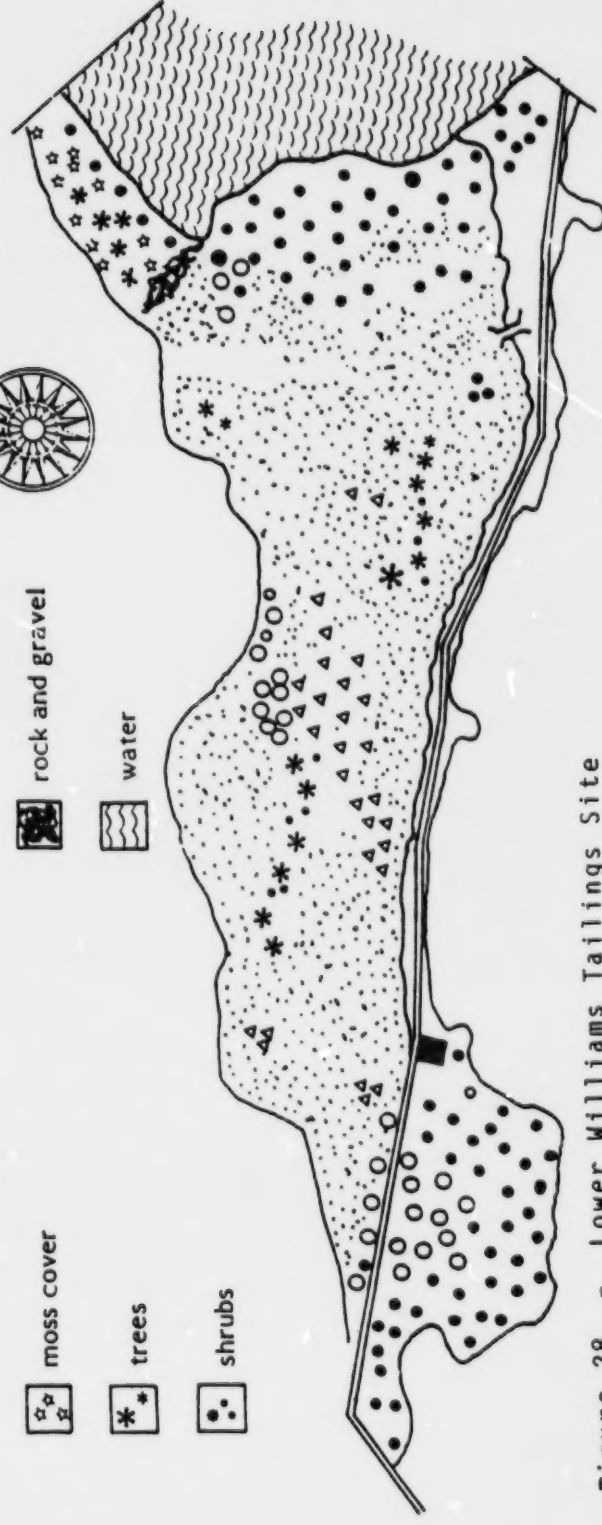


Figure 28 - Lower Williams Tailings Site
(from Kalin, 1983)

2.5.4 Cluff Lake

The Cluff Mining operation in northern Saskatchewan, operated by Amok Ltd., consists of 2 separate operating phases.

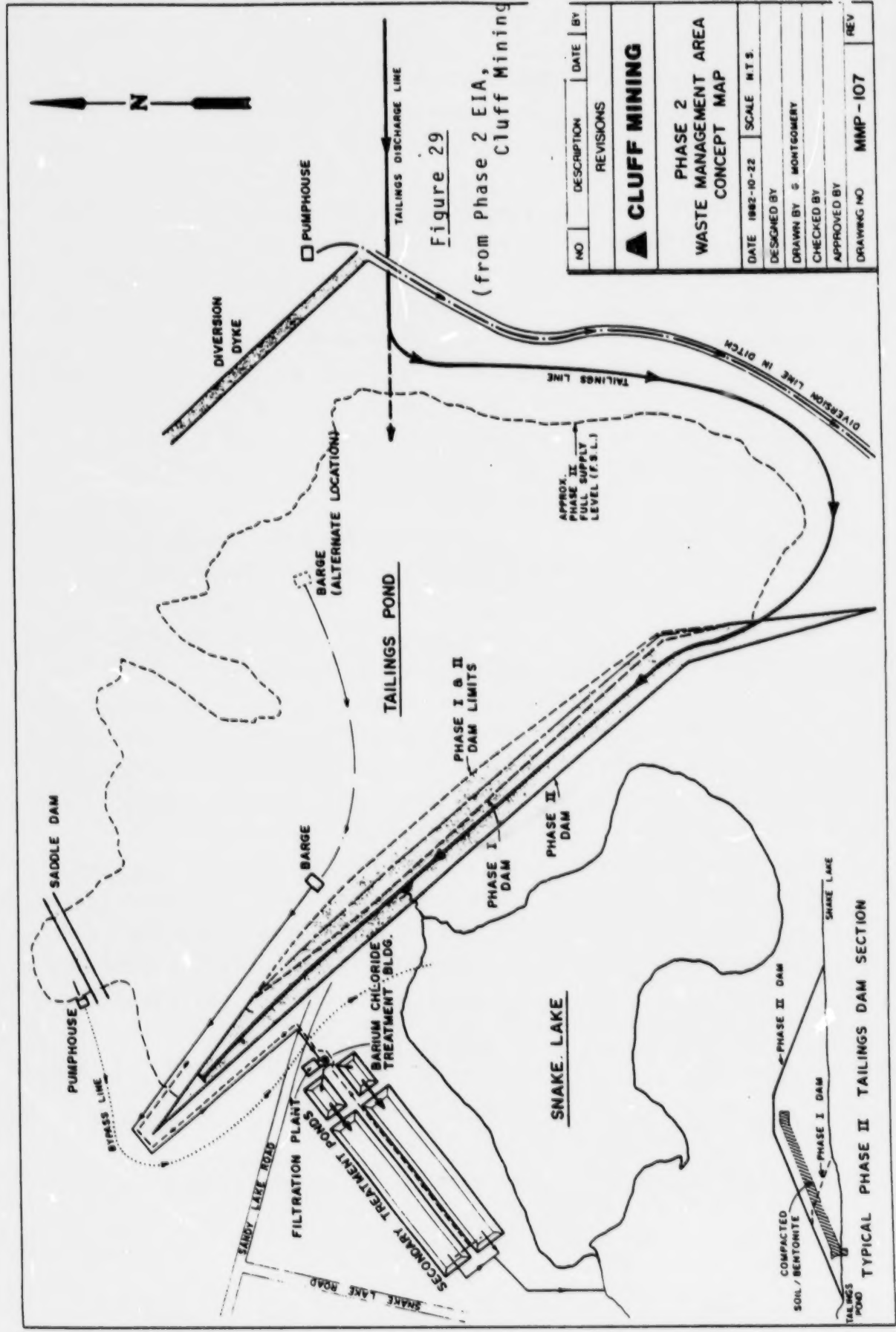
The Phase 1 operation, started in 1981, included the treatment of the very high-grade "D" orebody with a milling process consisting of gravity concentration, acid leaching, and direct precipitation of the leach liquor with magnesia. This operating phase was completed in early 1983 at which time the re-processing of gravimetric residues was initiated as an extension of the Phase 1 operation. This will continue to operate until 1984.

The Phase 2 operation which is currently being planned and due to start in late 1984, will be recovering uranium from lower grade (0.5% U_3O_8) ore deposits in the area using a conventional acid leach, CCD and solvent extraction circuit followed by magnesia precipitation in the existing facilities. The planned throughput is 230,000 tonnes/year.

The wastes from the Phase 1 operation included the leach residues, which are presently contained in concrete bins stored under cover on surface, and waste solutions containing a minimal amount of precipitates

The leach residues presently stored on surface total approximately 8,000 tonnes. Although a reasonable alternative is to treat this highly radioactive material during the Phase 2 operation, final plans have not been formulated.

The waste solutions from Phase 1, as well as minewater, reported to the waste management area shown in Figure 29. The dam construction is made impervious with a bentonite seal extending to bedrock. The bottom of the containment area consists of the natural ground in the area.



Decant solution is treated in the secondary treatment system (STS) with BaCl_2 and a polymer. The treated effluent is clarified in settling ponds and dual-media sand filters prior to discharge to the environment.

Solid tailings from the gravimetric residue reprocessing phase will be neutralized and discharged to the present waste management area. Decant solution will continue to be treated in the STS.

The present proposal for tailings impoundment during the Phase 2 operation is to use the existing waste management area and to increase the height of the Phase 1 dam to provide the required storage capacity. Decant solutions and excess minewater, would continue to be treated in the STS. Although this is a viable placement method other alternatives are currently being contemplated. These include the use of a cone, or flattened-cone, placement method in the existing facility or temporary storage in the existing facility followed by disposal of the tailings slurry in the Claude open-pit once mining activities are completed for the Claude orebody. Tailings in the existing area would then be transferred to the Claude pit at the appropriate time. Decant solution would continue to be treated in the STS. Close-out modelling studies have been commissioned for these alternatives.

In light of the various alternatives being assessed for the Cluff Mining operations, a review of information and data as it becomes available will prove useful to the N.U.T.P. In addition, the as-installed monitoring instrumentation for the waste management area will generate reliable field data for input into the N.U.T.P. Furthermore, monitoring in the vicinity of the mined-out "D" pit may also provide useful field data.

2.5.5 Rabbit Lake

The Rabbit Lake operation, located on the west side of

Wollaston Lake in northern Saskatchewan, was started-up in 1975 by Gulf Minerals and taken over by Eldor Mines Ltd. in late 1982.

The current milling process uses an acid-leach circuit, CCD's, and solvent extraction followed by ammonia precipitation. The plant is operated at 1500 to 2000 t/day with neutralized tailings discharged to a tailings basin constructed by damming a large natural depression. Approximately 3,500,000 tonnes of tailings have been discharged to date.

The tailings decant water is treated with BaCl_2 and polymer to remove radium and clarified in a series of three settling ponds prior to discharge to Hidden Bay. A sand filter has been installed and a portion of the treated effluent is clarified in this circuit. The waste management area is shown in Figure 30.

Although heavy metal and radionuclide levels have been acceptable with the current treatment system, elevated ammonia levels in the effluent have presented problems in the past. The use of ammonia will no longer be required in the proposed circuit for the Collins Bay ore and thus future problems are not anticipated.

Close-out procedures for this tailings area will need to be formulated since Rabbit Lake ore will be exhausted by 1985. The tailings disposal method proposed for Collins Bay ore will likely have a bearing on the close-out options to be evaluated for the Rabbit Lake tailings.

2.6 New Tailings Sites

2.6.1 General

New uranium operations which are committed to start up in the

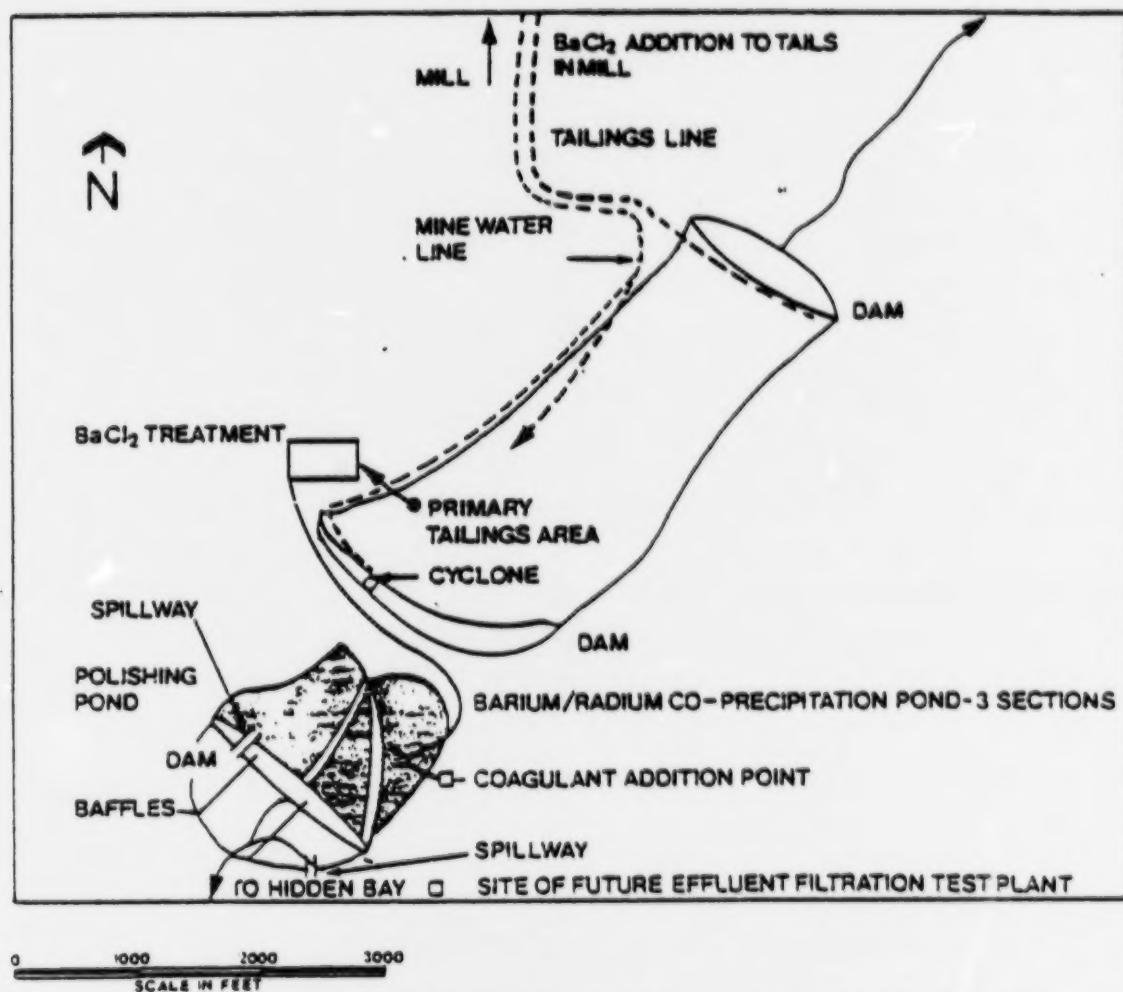


Figure 30- Rabbit Lake Tailings System

**URANIUM TAILINGS MANAGEMENT SYSTEM
NORTHERN SASKATCHEWAN:
GULF MINERALS, WOLLASTON LAKE**

(from Kilborn, Beak, 1979)

near future include the Key Lake Project in northern Saskatchewan, with a planned start-up in the latter half of 1983, and the re-activated Stanleigh Mine in Elliot Lake, Ontario with a start-up date of July 1983. The Eldor Mines Ltd. Collins Bay Project, a continuing phase of the existing Rabbit Lake operation, is slated to start-up in mid-1984 and the Phase 2 stage of the Cluff Mining operations is due for start-up in late 1984 (discussed in Section 2.5.4). A list of the new projects with their respective mill capacity is given in Table 3.

2.6.2 Key Lake

The Key Lake Project, operated by Key Lake Mining Corporation, is located approximately 200 km north of LaRonge, Sask. The ore is a high-grade (2% U_3O_8) uranium ore containing high levels of heavy metals and arsenic as contaminants. Radionuclides consist of radium and uranium with very low thorium levels.

The milling circuit, with a capacity of approximately 700 tonnes per day, consists of a 2-stage acid leach with CCD thickeners and solvent extraction for uranium recovery and purification. Uranium will be precipitated with ammonia and an ammonium sulphate crystallization plant will ensure acceptable ammonia levels in the final effluent.

Leach residues will be neutralized with lime and discharged to the tailings area with waste precipitates from the separate waste solution treatment circuit.

Treated effluent will be clarified using clarifying thickeners and pre-coat filters and discharged to monitoring ponds for check-analysis prior to being discharged to the environment. This mechanical separation of waste precipitates from treated effluents should prove to be much more efficient than settling ponds.

The bulk tailings will be pumped to a tailings containment area as a 35-40% solids slurry. The tailings area is being constructed to accomodate a layered tailings deposition technique. The construction basically consists of a bentonite seal, underdrains, and a sand filter bed for collection of seepage and runoff during the deposition phase. Tailings will be systematically placed in layers, approximately 100 mm in depth, and allowed to consolidate by evaporation and drainage. In cold weather, end discharge will be practiced in selected sections of the tailings site. These thicker layers will be allowed to consolidate over a certain time period prior to the placement of further tailings. The discontinuity effect of these thicker layers on the system will need to be determined.

The concept of this tailings placement method is to have a potential "walk-away" tailings containment area upon decommissioning. The systematic layered deposition method is to provide a partially saturated, moisture-retaining, tailings mass of low permeability which will result in negligible seepage after a few years of operation. On close-out, treatment of seepage and runoff water would therefore not be required.

Although operating problems can be anticipated with this type of placement method, especially under cold weather operations, the concept is certainly acceptable in light of its potential as a walk-away situation. The extensive instrumentation of this site will generate reliable and useful field data for evaluation of this tailings placement method. This operation should provide significant input into the N.U.T.P.

2.6.3 Collins Bay

The Collins Bay B-Zone orebody will be milled in the existing Rabbit Lake mill with some circuit modifications to accomodate

the varying mineralogy of this ore compared to the Rabbit Lake ore. The main differences of this ore are its arsenic content as well as other minor constituents which could affect the quality of the final uranium product. Changes to the Rabbit Lake circuit will include, the use of strong-acid stripping for solvent extraction, the use of hydrogen peroxide for uranium precipitation and modifications to the waste treatment circuit for efficient removal of contaminants from minewater and mill effluents.

The tailings disposal method which has been approved for this operation is in-pit disposal using the old Rabbit Lake open-pit to contain all the tailings from milling Collins Bay B-Zone ore.

The tailings will be dewatered by filtration in the mill in order to accelerate the consolidation of tailings when placed in the pit. The pit envelope will be pervious on all sides and at the bottom. The remaining tailings water from tailings consolidation in the pit will be collected at the base of the pit and pumped via a raise to surface and then to the effluent treatment plant. Sand filters will be used for clarification of final effluents.

During the operating phase, the water table will be kept below the bottom of the pit (by pumping of seepage and groundwater) to allow consolidation of tailings, and on close-out the surface of the tailings will be covered with a soil cover and the pit area allowed to return to its natural state, Rabbit Lake. Thus, the tailings mass will be isolated beneath Rabbit Lake and groundwater will flow around the tailings due to a lowering of the hydraulic gradient caused by the pervious envelope around the consolidated tailings mass. An illustration of this scheme is given in Figure 31.

This below-ground tailings disposal method will advance the state-of-the-art for this method of uranium tailings disposal with field instrumentation generating the necessary data for a full evaluation of the concept. This should provide useful information which may be applicable in the latter stages of the N.U.T.P.

2.6.4 Stanleigh

The Stanleigh Mine, located in Elliot Lake, Ontario, is presently being re-activated by Rio Algom Limited with a planned start-up date of July 1983.

The Stanleigh mill was previously operated from 1958 to 1960 and the tailings were discharged to the Crotch Lake tailings area along with tailings from the Milliken operation which ran from 1958 to 1964. A total of approximately 7,500,000 tonnes of tailings were deposited from these 2 operations.

The new Stanleigh mill operation will have a capacity of 4250 t/day with neutralized tailings being pumped to an expanded Crotch Lake tailings area. Tailings area decant water, which is acidic, will be treated with BaCl_2 and lime and clarified with dual media sand filters in a new treatment plant located at the discharge end of Crotch Lake. Sand filter backwash, containing the radium sludge, will be returned to the tailings basin by pumping underwater towards the area of tailings deposition. This method will allow the radium sludge to mix with encroaching tailings during settling. The use of sand filters for clarification should prove to be much more efficient than the conventional settling ponds that have been used to date in the Elliot Lake area.

3. WASTE DISPOSAL TECHNOLOGIES

3.1 Introduction

The above description of tailings sites provides an indication of the numerous aspects that need to be considered for uranium tailings management practice.

In order to provide a framework for consideration of research options that may be suitable for the N.U.T.P. various aspects of tailings management are detailed below. The topics covered include aspects related to the tailings management site as well in-mill processes for possible tailings modification.

3.2 Site Selection

The current activities of Eldorado Resources Limited in the close-out of the Beaverlodge operation underline the importance of site selection as the initial step to provide a tailings management area which on close-out, provides little difficulty in ensuring the safe long-term containment of uranium tailings.

Past practice of Canadian operations was to use natural topographic basins as impoundment facilities with retaining dams constructed of local burrow materials or tailings sands to confine the tailings to a specific area. Such aspects as watershed systems and seepage were not considered in these early site selections.

Currently site selection and environmental baseline studies play an important part in the initial planning of a uranium property. Preliminary site investigations include such items as topography, climate, hydrology, geology, hydrogeology, seismicity, stratigraphy, soil properties, and availability

of local materials for dam construction and use as liners.

Once a preferred site has been identified accurate mapping and climate measurements are carried out and detailed hydrogeology studies are done to assess runoff volume and flows that may enter the tailings catchment area. Detailed geotechnical investigations are also done to determine the soil and bedrock characteristics and the hydrogeology of the area is determined with respect to the local and regional groundwater regimes. The availability of materials suitable for dam and dyke construction and for use as impervious lining is assessed. Instrumentation and monitoring include the use of piezometers for determining the quality of various aquifers.

The site selection elements used in assessing an area for possible tailings containment have been listed by Robertson (1980). These are:

- i) Visibility
 - prominence
 - proximity to public
- ii) Land use/Ecological
 - mineralization potential
 - endangered species
 - wildlife habitat and quality
 - sensitive or unique ecosystem
 - watershed quality
 - vegetation type
 - scenic value
 - archeologic value
 - elevation
 - area of disturbance
 - proximity and size of human habitation
 - recreation land uses
 - economic land uses
 - roads and other public facilities
 - ownership

- iii) Airborne Release - exposure to prevailing winds
 - wind speed
 - impoundment surface area
- iv) Seepage Release - underlying rock types
 - surficial soils
 - foundation permeability
 - groundwater discharge area
 - flood plain
 - groundwater quality and location
 - surface water quality
 - existing streams
- v) Stability Release- topography
 - upstream drainage area
 - foundation strength and compressibility
 - proximity to perennial streams or rivers
 - location of flood plains
 - embankment height
- vi) Operational
 - distance and elevation from mill
 - capacity
 - access
 - type of tailings placement
 - technical feasibility
 - expansion capability
 - availability of construction and reclama-
tion material

3.3 Impoundment Techniques

3.3.1 General

The method of tailings disposal varies from site to site and depends on the site-specific nature of the local area. The two broad categories of tailings containment include surface disposal which require the construction of engineered embankments on surface and sub-surface disposal where tailings are placed below ground.

3.3.2 Surface Disposal

3.3.2.1 Dam Construction

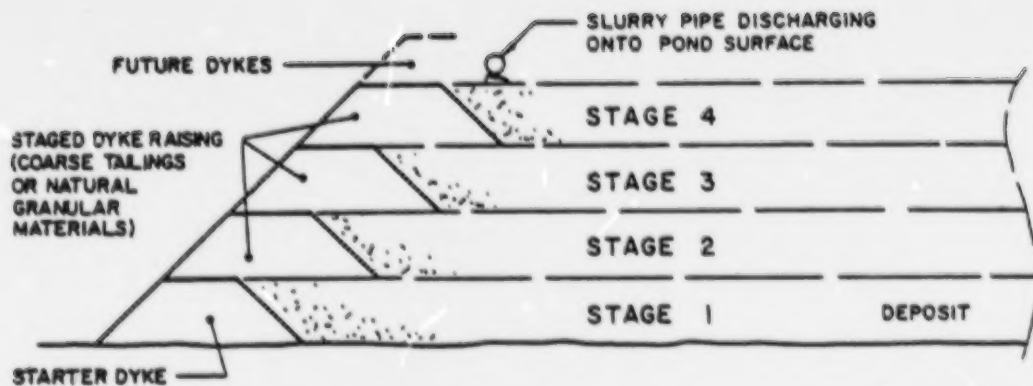
Surface tailings impoundment facilities necessitate the construction of dams to retain the tailings in a confined area. Former construction methods for retention dams are illustrated in Figure 32. These included the upstream and downstream methods where coarse tailings or local granular material were used to raise the dam heights as required. In the downstream method a synthetic liner could be used for reducing seepage.

The ineffectiveness of upstream dams has been well exemplified in Canada by the conditions at the numerous abandoned tailings areas. In fact, a dam constructed of coarse tailings at the Stanrock site failed and resulted in discharge of tailings downstream for several kilometres. In addition, the acid-generating capacity of the tailings creates direct contaminant runoff at the dam wall.

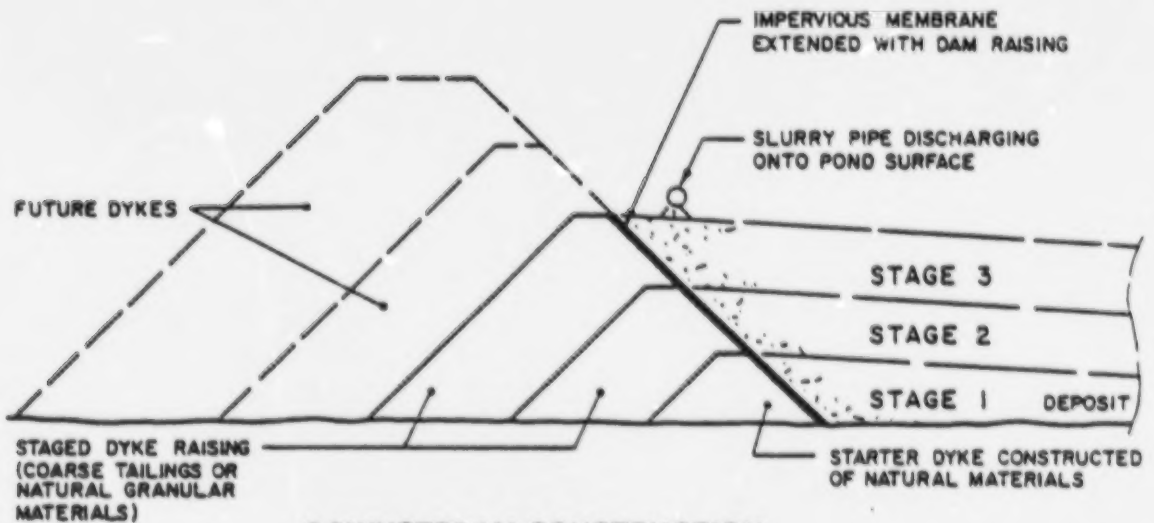
Engineered embankments for modern operations must now be made impervious using an impervious liner of clay, bentonite or synthetic material. Typical embankment configurations are illustrated in Figure 33.

The removal of tailings water in the tailings ponds can be accomplished by the use of a pump barge, as shown in Figure 34, or by an underdrain system as designed for the layered tailings placement method at Key Lake. This tailings water is reused in the mill process or is treated for contaminant removal prior to discharge.

Settling ponds for effluent clarification, or for use as monitoring ponds, must be made impervious with clay, bentonite,



UPSTREAM CONSTRUCTION



DOWNSTREAM CONSTRUCTION

Figure 32

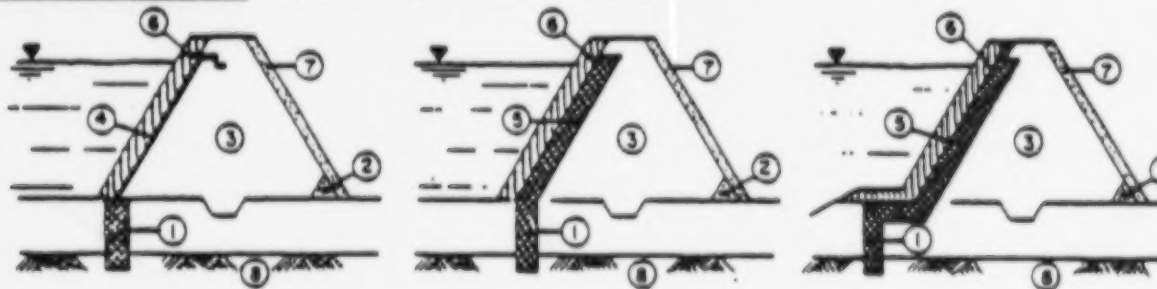
TYPICAL TAILINGS RETENTION DAM FORMER CONSTRUCTION METHODS

(from Kilborn, Beak, 1979)

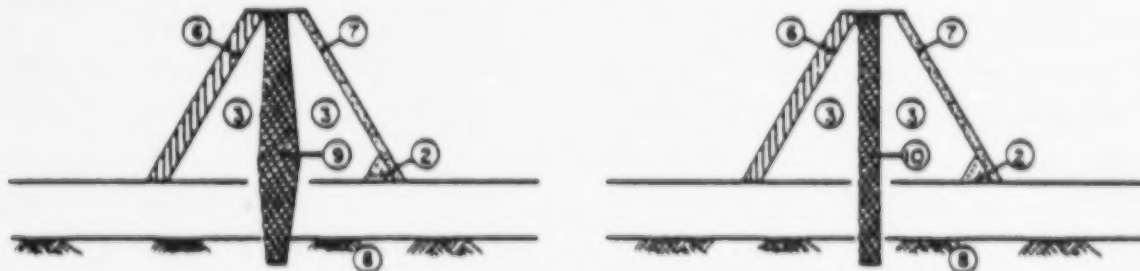
Figure 33

ENGINEERED EMBANKMENT ALTERNATIVES.

(from Kilborn, Beak, 1979)

ALTERNATIVE #1. UPSTREAM CUTOFF SYSTEMS.

1. Cutoff Wall - Clay, Bentonite/Soil, or Concrete keyed to impervious layer
2. Downstream Toe Drain - Sand/Gravel
3. Earth Fill
4. Synthetic Membrane - PVC, CPE
5. Upstream Impervious Blanket - Clay, Bentonite/Soil
6. Upstream Erosion Protection Blanket - Sand, Gravel, Rip Rap or Soil Cement
7. Downstream Erosion Protection - Seed, Sod, Mulch or Soil Cement
8. Impervious Strata

ALTERNATIVE #2. CENTRE CORE CUTOFF SYSTEMS

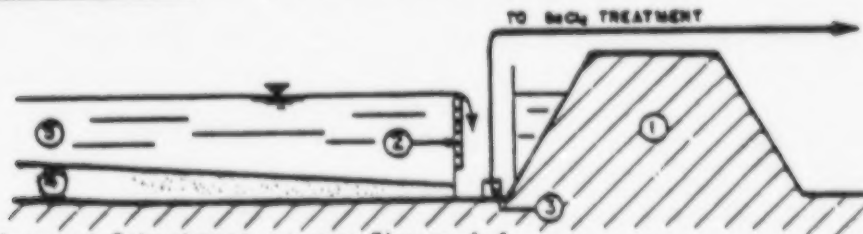
9. Centre Core - Clay, Bentonite/Soil
10. Centre Core - Diaphragm Wall - Bentonite/Soil, Concrete

Figure 34- Alternative Decant Systems

ALTERNATIVE DISCHARGE STRUCTURE AT TAILINGS PONDS.

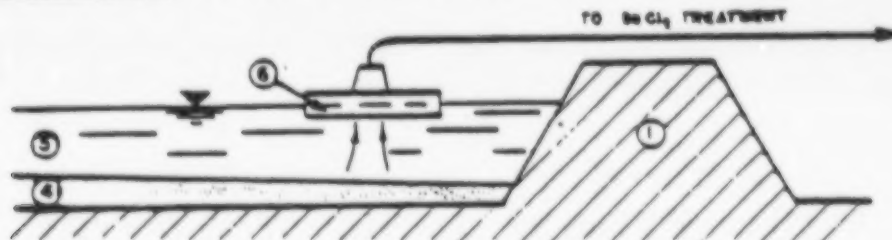
(from Kilborn, Beak, 1979)

ALTERNATIVE # 1. DECANT TOWER AND PUMP SYSTEM.



- ① Engineered Embankment as per Figure 4.6
- ② Decant Tower - clarified effluent overflows into pump chamber
- ③ Submersible Pump(s)
- ④ Settled Tailings and Precipitate: Ra-226, Th-230, Metals, Silicates
- ⑤ Neutralized/Clarified Tailings Effluent

ALTERNATIVE # 2. FLOATING PUMP BARGE.



- ⑥ Floating Pump Barge - Aeration/Bubbler system for winter operation

ALTERNATIVE # 3. DISCHARGE THROUGH EMBANKMENT.



- ⑦ Conventional Decant Tower/Gravity Pipe - potential embankment failure mechanism
- ⑧ Reinforced Concrete & Stop Log weir spillway
 - expensive and must be periodically raised
 - potential embankment failure mechanism

Figure 34

synthetic membranes, asphalt or concrete. Liners are discussed further in Section 3.4.

3.3.2.2. Placement Methods

Placement methods for surface impoundment areas include the wet discharge method, as practiced in the operations at Elliot Lake, Ontario, thickened tailings discharge, layered tailings deposition and filtered tailings discharge. The use of cycloned tailings discharge for separation of sands from slimes would be required for upstream dam construction. As this method is no longer applicable for uranium tailings impoundments the use of cyclones need not be considered in this context but will be referred to later with respect to tailings modification.

Wet Discharge

In the wet discharge method neutralized tailings pulp from the mill is pumped to the tailings area where lateral segregation of coarse and fines occurs from the point of discharge. The slimes settle out and clear decant water is removed for treatment and discharge. A single spigot or multiple spigots can be used for this application.

This method results in a substantially saturated tailings deposit with zones of unconsolidated slimes. The high water table provides a high pressure head which increases the rate of seepage from the tailings area. On close-out the large areas of slimes that are present can lead to difficulties in reclamation.

Thickened Tailings

The cone discharge of thickened tailings is being evaluated

at Denison in order to increase the capacity of the Long Lake tailings basin. In addition to resulting in an increase in storage capacity, the final contour of the tailings surface will be better suited for reclamation at close-out. Also, the continuous slope which develops with this method of discharge is suited to shedding of surface water rather than infiltration and should therefore result in less seepage.

Layered Tailings

The layered deposition of tailings will be used at the Key Lake operation as described in Section 2.6.2.

The deposition of tailings in thin layers with a 1° slope results in vertical classification of sands and slimes in each layer. Successive layers of tailings deposited on the beaches result in a stratified deposit of tailings with low permeability and thus input water reports mostly as runoff instead of seeping through the tailings.

Consolidation of the tailings is achieved by evaporation and by removal of excess water via underdrains installed below the tailings.

The slimes that concentrate at the top of the layers will tend to form a crust on drying and thus wind erosion problems can be minimized during the drying phase. Also, seepage and runoff water can be recycled to the dam as sprays in order to increase the net evaporation of tailings water and to keep the tailings surface damp.

On decommissioning the tailings are left in a consolidated state with moisture retaining capacity.

The concept of layered tailings has been applied for many years in South Africa and the above benefits of this method

have been proven. However, the severe cold northern climate typical of northern Saskatchewan will require the deposition of thicker layers during the winter months and the effect of this discontinuity on the system is not known. Other field problems that may occur include surface cracking, which may increase permeability, and the possibility of lateral segregation due to variations of tailings pulp densities. This could result in increased seepage at the sandy zones near the point of discharge.

The application of this method at Key Lake will greatly advance the state-of-the-art of this deposition technique in Canada. The field data generating from this tailings site should be assimilated in the N.U.T.P.

Filtered Tailings

The proposed in-pit tailings disposal method for the Collins Bay B-Zone Project will require filtration of the tailings in the mill prior to disposal. Filtration is carried out in order to accelerate consolidation of the tailings when placed in the pit. In turn this provides recycle water for the mill process. Collins Bay will be the first major application of filtered tailings in Canada.

Filtered tailings could also be deposited in surface impoundments in order to reduce the area requirement for tailings sites as well as providing consolidated tailings for enhancing close-out procedures.

The higher cost of filtered tailings deposition, due to trucking or conveying requirements, compared to more conventional systems precludes it from being included in current uranium plant designs. Experience from the Collins Bay Project may result in more interest for this method of deposition.

3.3.3 Subsurface Disposal

3.3.3.1 Pit

The first Canadian application of in-pit disposal of tailings in a mined-out pit will be the Collins Bay B-Zone Project in northern Saskatchewan.

The tailings originating from milling Collins Bay ore will be filtered and deposited in the mined-out Rabbit Lake pit. In order to avoid contamination of groundwater a zone of coarse rock and sand will be placed between the pit wall and the tailings thereby causing a hydraulic "short-circuit" which will prevent interactions between groundwater and tailings water.

As described in Section 2.6.3, tailings water will be collected and treated during the operating phase and for a certain period during the transition phase. Final decommissioning will allow the overlying lake basin to return to its original state as a water body.

In-pit disposal is being practiced in the United States at Union Carbide Gas Hills Plant where the pit bottom and sidewalls were lined with clay and the water originating from the hydraulically-placed tailings was reclaimed through an in-pit filter blanket and submersible pumps for pumping to lined evaporation ponds.

The main advantage to in-pit disposal results in the complete isolation of the tailings on decommissioning. Gamma radiation and radon emanation is virtually eliminated, erosion problems are non-existent and there is no need to have an on-going monitoring and maintenance program after decommissioning.

Although this scheme is very site-specific (basic requirement is a mined-out pit) the advantages cited above make it a promising disposal alternative. Field monitoring of the Collins Bay operation will allow a reliable assessment of this scheme.

3.3.3.2 Mine Backfill

The use of classified mill tailings mixed with cement for use as ground support medium in cut-and-fill mining method has been practiced at Madawaska and Beaverlodge. Denison is introducing it at their operation for secondary pillar recovery. This mining method results in approximately half the mill tailings being returned underground with the remaining half, the slimes, requiring separate containment on surface.

A greater use of tailings fines in backfill operations may be possible by employing slime modification techniques such as flocculation, solidification or electrokinetic densification. Further investigations would be required to assess the suitability of these techniques.

There is some concern however that the higher levels of radium in the slimes fraction of tailings could present problems for backfill operations due to radon emanation if a greater use of the fine fraction was practiced. Also, possible contamination effects on the groundwater by backfill-placed tailings is not known and further investigations may be necessary in this area. The use of shotcrete wall lining and the use of cement or bentonite additions could be areas for further study.

The placement of tailings in abandoned and exhausted mines or in mined-out stopes in active mines, could be considered for both currently-produced tailings or abandoned tailings. The technique of choice would be to attempt the separation of the fine and coarse fractions with the slimes being placed underground and the coarse, with its lower radionuclide content, stored on surface. Although this possibility may be technically feasible it would likely prove to be too costly and, more important, it would preclude future mining activities in selected mines. This would not be acceptable as market conditions and improving technologies have resulted in certain mines being re-activated after a period of dormancy.

Overall then the use of mine backfill methods should be encouraged since it reduces the total amount of tailings requiring surface containment. Investigations related to mine backfill should be part of the N.U.T.P.

3.3.3.3 Deep Lake

The possibility of deep lake disposal of tailings has been considered for the Elliot Lake operations since this would eliminate the longterm problem of acid generation. A water cover has been shown to retard acid generation for pyritic tailings at certain abandoned tailings sites in Elliot Lake.

In addition, lakes are depositional environments and the tailings at the bottom of a lake would, with time, be covered with lake sediments. This would reduce the exchange of contaminants between the tailings mass and the overlying water. The isolation of the tailings could be further enhanced by the placement of a clay or bentonite layer over the tailings after tailings placement is completed.

In a suitable lake a stable, stagnant bottom layer of water would be isolated from the upper layers by a chemocline. This effect has been observed at the flooded Gunnar open pit in northern Saskatchewan. As a result, in a lake with downward hydraulic gradients, any potential contaminant release from

the solid tailings would remain in this stagnant bottom layer.

Tailings in a deep lake disposal scheme could be considered as being completely isolated from the surface and gamma radiation and radon emanation would be eliminated. Although many technical uncertainties exist for this type of disposal method, the advantages of this method over surface storage options provides the justification for further evaluations of deep lake disposal.

3.3.3.4 Cellular

The use of specially excavated cells and trenches has been practiced in the United States for uranium tailings disposal.

The White Mesa mill in southeastern Utah features simultaneous construction, operation and reclamation of sequential cells lined with hypalon. The Sweetwater Project uses a 4-cell impoundment area lined with PVC with each cell excavated above the water table. Final reclamation includes a 0.6 m clay cap and a 3.5 m cover of local soils.

The Mt Taylor Project in New Mexico proposed the use of a series of parallel excavated trenches for hydraulic deposition of the slimes fraction of the tailings. The coarse fraction was to be used as mine backfill. The spoil from the excavated trench would be placed over the drained tailings placed in the previously filled trench. The Pioneer Project in Colorado proposes the disposal of dewatered tailings in a series of below-grade trenches.

Although these disposal options can be considered as alternatives they are costly and the site characteristics of uranium properties in Canada would preclude them from being viable options in this country.

3.4 Liners

3.4.1 General

The use of liners in tailings impoundments and in settling or monitoring ponds is practiced extensively in current containment construction. Types of liners available include natural clay soils or soils with bentonite or other additives. Numerous types of artificial liners are also available along with rigid liners such as concrete, asphalt or shotcrete.

3.4.2 Clays

The use of clay soils, if available locally, is widely used as lining material for seepage control. The advantages of clayey soils includes its low permeability (10^{-7} cm/sec), excellent neutralizing capabilities due to their cation exchange capacity, integrity, flexibility, and long-term stability.

In order to achieve minimum permeability of in-placed clay soils it is imperative that placement moisture levels be controlled and that the compaction operation be carried out under close supervision by appropriate personnel.

One potential problem with clay liners is the possible reaction of contaminants or chemicals in the tailings seepage with the clay soil. Cation exchange and acid attack could, in the long term, affect the chemistry of the clay soil and thus possibly increase permeability. Further research would seem to be warranted in this area in order to assess long-term integrity.

3.4.3 Additives

The use of bentonite as an additive in soils in proportions of

2 to 10 per cent by weight can be used to reduce the permeability of soils with high permeabilities by filling the void space of the compacted material. Till with bentonite has been used in the construction of the tailings area at Key Lake. Contaminant-resistant treatment additives, such as Saline Seal 100, are available for preventing deterioration of the liner by tailings seepage.

Chemical dispersants such as sodium phosphates, carbonate, silicate or chloride can be used as additives to modify the structure of a clay material, thereby decreasing its permeability even further. This is especially applicable to clays high in calcium and magnesium but low in sodium.

3.4.4 Artificial Liners

Artificial liners include thermoplastic membranes, synthetic rubber membranes, asphalt emulsions and rigid liners.

The thermoplastic membranes available include polyvinyl chloride (PVC), polyethylene, chlorosulfonated polyethylene (hypalon), chlorinated polyethylene (CPE), and elasticized polyolefin (Dupont 3110).

The poor weathering characteristics of PVC have precluded its use in most operations even though it is the lowest cost material. Hypalon, although twice as expensive as PVC, is the most common plastic liner used because of its resistance to effluents, kerosene and sunlight. CPE may find more application in time as it has similar properties to hypalon and is less expensive. Polyethylene is difficult to apply due to its stiffness and the Dupont 3110 product is susceptible to kerosene attack. A combination of a PVC bottom and hypalon walls has been used in certain cases in order to lower total liner costs.

A typical permeability value for hypalon liners is 10^{-10} cm/sec but actual field permeabilities could be greater due to possible leakage through pinholes or through seams. In addition, the effect of the tailings mass above the liner will apply a certain magnitude of stress which could result in some type of failure mechanism.

The long-term integrity of plastic liners can probably be assured for a period of 15 to 20 years but predictions beyond this would be difficult to make with the present knowledge available. It seems apparent that some form of investigation will be required to determine the suitability of plastic liners for long-term containment.

3.5 Subsurface Flow Barriers

The use of subsurface flow barriers provide a means of controlling seepage in areas where permeable soils of moderate depth cover a relatively shallow impermeable bedrock.

Grout curtains can be used for reducing hydraulic flow by pumping cement or chemicals down a borehole and injecting the mixture into rock joints, fractures or soil pores. Available materials include silicate-aluminate, cement, clay-oil, silicon halides, epoxy resins, molten sulfur or polyurethane. A cement grout is only applicable for neutral or alkaline areas. The use of a grout curtain at Madawaska was successful in reducing seepage into Bentley Lake but it did not eliminate it completely. One beneficial effect that was noticed was the adsorption quality of the grout curtain material for removing radium from the seepage water.

Slurry walls involve the excavation of open-trenches or interconnected large-diameter borings which expose all

permeable formations that may transmit seepage. A slurry of powdered bentonite is then mixed with the materials obtained from the excavation and this mixture is pumped back in.

Barrier wells can be drilled into permeable formations to raise local groundwater levels in order to induce a reversal of hydraulic gradients back toward the source of seepage.

Collector ditches and wells can also be used for collecting containment seepage and runoff for treatment.

3.6 Effluent Treatment

The requirement of waste treatment in uranium operations include the neutralization of residue, treatment of mill waste solutions, treatment of contaminated minewater and treatment of tailings seepage and runoff at active and inactive tailings sites.

Effluent treatment can either be carried out in the mill as part of the complete mill process or at the tailings management area where secondary treatment of the tailings supernatant or seepage water is carried out for radium removal.

Both methods are used in northern Saskatchewan. At Rabbit Lake, leach residue tailings and waste solutions are bulk-neutralized with lime in the mill and the combined tailings slurry is pumped to the tailings containment area. Tailings water is then treated with barium chloride and coagulant for radium removal. Settling ponds are being used for effluent clarification but a sand filter unit is also used for clarification of part of the flow. The Collins Bay Project will include sand filters in the design for positive removal of radium precipitates from treated effluent water.

The Cluff Lake operation is using a similar system of bulk neutralization for the leach residue and raffinate solution. Tailings water is treated in a secondary treatment system with barium chloride and alum. Radium sludge removal is accomplished in a settling pond followed by sand filters which were installed during the operating phase of the project. Excellent radium levels are being achieved for the final effluent.

The Key Lake Project will be neutralizing waste solutions and treating for radium removal as part of the mill process. Removal of precipitates from treated solutions will be accomplished mechanically by the use of clarifying thickeners and filters. These waste products, containing calcium sulphates and arsenates, iron hydroxides, heavy metal precipitates and radium precipitates, will be combined with the neutralized leach residue for disposal as a mixture in the tailings area. Clarified effluent will be collected in monitoring ponds for check analysis prior to release to the environment. This system allows the contaminant precipitates and solid tailings to be mixed prior to disposal and therefore eliminates the problem of waste sludge build-up in settling ponds. The use of filters for final clarification can also be expected to be much more efficient than settling ponds for removal of the fine precipitates that are produced in waste treatment circuits. The proposed circuit for the Midwest Project also includes mechanical thickening and filtration as part of the design for waste solution treatment.

At Madawaska, excess tailings water which was not re-used in the process is treated for radium removal by the addition of barium chloride and clarification was carried out in a settling pond followed by a gravel bed where the treated

effluent discharged to the groundwater. This system is unique in that the gravel bed not only clarifies the effluent but also acts as a collector for radium due to its inherent adsorption characteristics.

In Elliot Lake the existing operations (Quirke, Panel, Denison) bulk-neutralize waste materials in the mill and treat tailings decant water at the tailings site for radium removal. Although regulatory radium levels are currently being met the build-up of waste sludge in the settling ponds used for clarification could present problems in the near future.

The Panel operation is using hypalon-lined, baffled, settling ponds. Good results are being achieved but sludge build-up is becoming evident in the front sections of the ponds.

The Stanleigh Project has included a well-engineered effluent treatment plant in the project design. Crotch Lake tailings area runoff will be treated with lime and barium chloride for neutralization and radium removal. The treated effluent will be clarified in dual-media sand filters and sand filter backwash, containing the fine precipitates, will be pumped back underwater into the tailings area. The encroaching tailings will settle over the precipitate sludge thereby assisting in settling and immobilization of the wastes.

The treatment of contaminated seepage and runoff at Beaverlodge and at inactive tailings sites in the Elliot Lake area is resulting in the build-up of waste sludge in dedicated lakes or ponds. This can be considered as one of the major problems which will need to be addressed for the long-term close-out of these inactive sites.

In summary, the use of mechanical equipment for liquid-solid

separation and clarification of treated effluents will likely become common place in future uranium plant designs. This will allow the physical immobilization of the waste sludges within the solid tailings matrix and also provide excellent clarification of treated effluents prior to release to the environment. Problems which still need to be addressed include the removal and permanent disposal of waste sludges in the settling ponds at active and inactive tailings sites as well as the potential re-dissolution of contaminants in these sludges after disposal.

3.7 Tailings Modification

3.7.1 General

The many problems associated with uranium tailings containment at existing active and inactive sites has led to investigations into the possibility of producing innocuous tailings for disposal as well as investigations into possible modifications to tailings to make them suitable for long-term storage. The various alternatives available for application or research are described below.

3.7.2 Ore Beneficiation

The main interest in ore beneficiation in the past has been to reduce the amount of ore to be treated by discarding a low-grade fraction and retaining the higher grade fraction for uranium recovery. The objective would be a decrease in capital and operating costs for the plant. Consequently, ore beneficiation can be considered as a possible means of reducing the total amount of tailings requiring disposal while providing a waste rock which would be relatively innocuous.

Radiometric ore sorting has been practiced in the past, and

currently in one U.S. operation, but results have shown that ore sorting is economically unattractive for Elliot Lake type ores. It may be more applicable to northern Saskatchewan ores due to their typical high grades. In any case, it is doubtful that waste rock could be produced with levels of uranium, radium and heavy metals sufficiently low to make the reject material innocuous.

Gravity concentration has been used for pre-concentration in the Phase 1 operation of Cluff Mining. The plant results showed that gravity tailings contain uranium in sufficient amounts to require reprocessing. Consequently, this method is not viable for possible reduction of tailings mass as the re-treatment of gravity tails would end up as leach tails from the plant.

Flotation processes are not practical for uranium concentration in mill ore feed but their application for pyrite removal is feasible. This is discussed in Section 3.7.4.

The use of wet high-intensity magnetic separation can be used for pre-concentration but is not applicable for removal of radionuclides from mill feed.

Work by CANMET has shown however that a combination of flotation, gravity concentration and magnetic separation could be used to provide a mill flowsheet for producing ore weight concentration ratios of 2:1 to 4:1 and acceptable recoveries of uranium, pyrite, radium and thorium. This may warrant further investigation but it must be remembered that, although relatively innocuous tailings can be disposed of before leaching, a substantial amount of leach tailings, with higher levels of radionuclides, will still require disposal.

3.7.3 Radium/Thorium Removal

The main concern with uranium tailings is the content of radionuclides which can continue to release radioactivity to the atmosphere for thousands of years. Consequently, if radium and thorium are removed from the tailings in the mill process the tailings can be made relatively innocuous with respect to radionuclides. Other heavy metal contaminants, such as in Saskatchewan operations, would be in a relatively stable form in the tailings mass as a result of waste solution treatment.

The removal of thorium from existing mills using acid leaching could be achieved by neutralizing the barren waste solutions separately with lime to produce a gypsum-thorium cake with a high activity. This circuit could be easily installed in existing operations to provide tailings with acceptable thorium levels. However, high radium levels in the tailings would still remain and safe containment of a high-activity thorium waste product would be required.

Other leaching agents have been investigated for providing the complete dissolution of uranium, thorium and radium in the mill feed. If an economic leaching agent can be found then unit processes could be established which would produce a uranium product for market and radium and thorium waste products for separate disposal. The bulk of the ore feed would then result as innocuous tailings after removal of these radionuclides. Leaching agents that have been tested include;

- sodium chloride
- nitric acid
- chlorine (high temperature chlorination)
- hydrochloric acid/calcium chloride
- ferric chloride
- EDTA

The use of sodium chloride is applicable for leaching radium from tailings. Processes envisaged include filtration of tailings after uranium recovery, leaching of radium with NaCl, washing of leached tailings and final disposal. Precipitation of the contained radium in the chloride liquor and disposal of this high activity sludge would be required. Uranium recovery would still be achieved with acid leaching, and thorium removal could be achieved by lime neutralization of the mill barren solutions.

The use of nitric acid as a lixiviant for uranium and thorium has been shown to be effective but costs of proposed circuits are estimated to be three times that of conventional circuits. Radium removal from the tailings by complexes such as EDTA is also necessary for pyrite ores since radium is not dissolved with nitric acid. This is likely due to the precipitation of radium by sulphates formed from the oxidation of pyrite in a nitric acid leach. However, a nitric acid leach may still be viable for uranium, thorium and radium removal for northern Saskatchewan ores due to their low pyrite content.

High temperature chlorination has been tested with some success but anticipated contaminant problems in off-gases has precluded it as a viable option.

Chloride metallurgy for uranium, thorium and radium leaching has been shown to be effective for Elliot Lake type ores but difficulties have been encountered with high-arsenic ores typical of northern Saskatchewan. Although costs are higher for proposed chloride circuits this lixiviant may be the only possible alternative for a leaching agent to recover uranium, radium and thorium in one circuit.

Radium and thorium recovery from leach solutions is another area which requires investigation if viable processes are

to be established for radium/thorium removal from tailings. Ion exchange processes using solid resin zeolites or strong acid cation resins have been identified as possibilities. Other possible avenues of investigations include reverse osmosis, barite adsorption, biosorption, and complexing with radium selective complexers (Dow XF-43230).

It becomes obvious that the concentrated radium and thorium waste products produced in these potential modified circuits would require special consideration for storage or long-term disposal. Research studies would be necessary to address this problem if viable processes are to be proven, both economically and technically, for application in future plants.

3.7.4 Pyrite Removal

Acid generation in Elliot Lake tailings is the major environmental concern for that area as described in Section 2. The generation of acid from the abandoned tailings at Lorado is also a problem at that site.

Acid generation causes tailings water to become acidic and through seepage and runoff, contaminants in the tailings are mobilized more readily by the acidic solutions. Hence environmental concerns include the need to neutralize the contained acidity as well as removing radionuclides from the acidic seepage and runoff. This has been described in Section 2.3.8 for the Nordic tailings site. At other sites the effect of acidic seepage on clay liners in tailings impoundments may result in increasing permeabilities due to possible chemical breakdown of the natural clay minerals.

Since acid generation is caused by the oxidation of pyrite in the tailings mass it is evident that removal of the pyrite would eliminate this serious long-term environmental problem.

Over 95% pyrite removal from the mill tailings can be achieved by the use of appropriate flotation circuits. This would reduce the pyrite content in tailings to a level which would eliminate the possibility of long-term acid generation.

Pyrite-free tailings could also be used as final placement covers over existing and abandoned tailings to minimize the oxidation of the existing pyritic tailings. Covers of sufficient thickness would prevent oxygen transfer to the pyritic tailings and, once vegetated, may provide a long-term solution to the abandonment of current, as well as abandoned, tailings sites. The problem of input water with its incipient oxygen content could be minimized by the placement of a layer with bentonite additions to reduce permeability and hence promote surface runoff.

The possibility of installing pyrite removal circuits at existing operations in Elliot Lake has never been seriously considered in the past due to economics and the eventual need for disposing of the concentrated, high radionuclide, pyrite concentrate in a safe containment area. Similarly, the reclamation of existing abandoned tailings for pyrite removal would be difficult to justify and is therefore not seen as a viable option.

However, recently the Elliot Lake operations have been investigating the possibility of recovering pyrite from tailings in existing operations and installing an acid plant for the purpose of producing sulphuric acid for use in area mills. The present high costs of acid from other suppliers is currently making this alternative more attractive.

It has been suggested that recovery of pyrite from tailings at the Denison and Quirke operations would be adequate to meet the acid requirements of the area operations. Pyrite-free

tailings could then be used for covering areas of pyritic tailings at these operations and possibly at other abandoned sites in the area. In view of the potential favourable economics this avenue should be pursued as it could assist in possible close-out procedures by supplying cover material for the tailings sites for inhibiting pyrite oxidation and minimizing acid generation.

3.7.5 Sand-slime Separation

It has been shown that the radium content, and to some extent the thorium content, in tailings is associated with the finer fractions due to re-precipitation of radium and adsorption on the solid tailings. Thus, if sand-slime separation of tailings was carried out it may be possible to reduce the radium content in the coarse fraction while increasing the radium content in the slime fraction. The coarse fraction could then be disposed of on surface in impoundments which could be of less concern due to the lower radium content. The slimes fraction would need to be disposed of in an impoundment with more stringent regulations or solidified in some manner to render them amenable for use as backfill. Overall then the tailings disposal problem may not be alleviated by this method. In fact this physical beneficiation method would actually result in two separate areas of tailings to be concerned with.

However, sand-slime separation may have a role to play in decreasing the permeabilities of tailings by using the low permeability characteristics of the slimes fraction of tailings. As discussed in Section 3.3.2.2., the layered tailings placement method is dependent on the vertical segregation of the coarse and fine fraction of tailings during deposition. There is some concern that lateral segregation may occur which would cause zones of high permeability in areas of coarse tailings.

Perhaps then, a physical separation of coarse and fine fractions by cyclones and alternating deposition of coarse and slimes in two distinct areas of a tailings impoundment would eliminate this potential for high permeability zones. In this way, definite successive layers of coarse and slimes would be built up thereby ensuring the full benefit of the low permeability slime layers for reducing seepage. As an extension to this, on close-out only the coarse fraction of tailings could be deposited during the latter stages of operation. An adequate cover of coarse tailings would thus provide lower radon emanation, due to its lower radium content, while providing a surface cover which could be more easily revegetated. The small amount of slimes produced near the end of operation could be returned underground or stored in a suitable facility on surface.

This scheme would seem to have some potential for improving on the layered tailings concept by physically ensuring the deposition of alternating coarse and fine layers. It provides an avenue for investigation in conjunction with the Key Lake operation over the next few years.

3.7.6 Immobilization

The immobilization of contaminants in tailings remains as a possible avenue of investigation if the surface storage of tailings becomes necessary in the long-term. Some possibilities that exist for tailings, as well as slimes fractions in sand-slime separation, are:

- the addition of adequate amounts of limestone in tailings could provide the buffering capacity for the acid-generating potential of the contained pyrite. There is some doubt however as to the immobilization of radium in adequately treated tailings. Radium mobility is still evident in neutral or alkaline tailings at other properties.

- the use of cement additives may provide some form of solidification but is likely not applicable to pyritic tailings due to acid generation and the resultant chemical attack on the cement additives.
- solidification of tailings by the addition of silicates is another area of investigation but long-term weathering effects would need to be overcome.
- agglomeration of tailings followed by fusion has been shown to result in a decrease in leaching rates of radium from tailings. This is probably due to the decrease in surface area and the inhibiting effect of the fused surface. Due to the potentially high costs of this option as well as the effect of long-term weathering, it seems unlikely that it can be a viable process.
- there has been suggestions made (CANMET) that sulfate ions generated by bacteria in pyritic tailings limits the solubility of radium. This effect can be assumed to be negligible based on the field data obtained at the Nordic tailings where high radium levels are present in seepage.

3.7.7 Consolidation

The consolidation of tailings by dewatering in the mill process using filtration, by layered tailings deposition or by thickened tailings discharge can provide a tailings area which enhances surface runoff of input water while providing a surface cover which is amenable to reclamation on close-out. These placement methods have been described in Section 3.3.2.2.

The installation of interior drains at abandoned tailings sites could be considered in order to provide consolidation of tailings and a lowering of the phreatic surface in the upper layers. Other possible consolidation techniques that could be considered include electro-osmosis, electrokinetic

methods, ultrasonic methods, evapo-transpiration by vegetation or the use of a "tailspinner" centrifuge.

The benefits of consolidation are seen as:

- reduction of potential seepage losses by decreasing the hydraulic head
- reduction in liquefaction potential
- reduction in possibility of dam failures
- provision for easier reclamation
- inhibition of seepage by upward movement of tailings water by capillary action

The above benefits for abandoned tailings sites would seem to warrant some degree of investigation efforts in this area. The modelling program can provide an insight into the potential benefits of consolidation with respect to long-term abandonment.

3.8 In-situ Leaching

The use of in-situ leaching for extraction of uranium has been practiced quite extensively in American operations and one operation is presently being planned in Australia. In general this method has been used to economically recover uranium from low-grade orebodies.

The operation involves the drilling of boreholes into the orebody and pumping lixiviant into the orebody using a specified pattern of boreholes. The lixiviant solution, either alkali or acid, dissolves the uranium in-situ. It is then pumped back to surface and the collected pregnant solution is purified and concentrated with ion exchange and the uranium is precipitated as a marketable product. The waste solution in American operations is re-injected underground in deep injection wells.

This method is a viable alternative to conventional mining and milling operations since it results in:

- minimum site disturbance
- no solids disposal requirements
- better economics

For Canadian properties it can be considered as a potential method for recovering uranium from the high-grade, localized orebodies typical of northern Saskatchewan. Although environmental concerns need to be addressed it is an alternative worth investigating since it would eliminate the need for disposal of solid tailings. In this respect it can be considered as a tailings modification method. If proven viable it will also eliminate the need to mine these high-grade orebodies by underground methods where radiation problems are a serious area of concern with respect to underground mining activities.

The main environmental concerns foreseen for an in-situ leach operation is field restoration once leaching is completed in a particular area and the possible contamination of the groundwater regime in the vicinity of the orebody. The main technical items needing attention are the leachability of the ore in an in-situ operation, the physical flow characteristics of the ore and surrounding material, the ultimate recovery of uranium possible in this type of operation, the problems that may be associated with field restoration, and the requirements for disposing of some waste solution or products as waste precipitates.

In the end the main criteria which will determine the viability of this method of uranium extraction is the ultimate uranium recovery possible from an orebody. The economics of such an operation for high-grade orebodies would need to be attractive and would therefore require a full assessment.

The associated technical areas of concern would need to be addressed thoroughly and, with sound engineering practice, an efficient operation meeting all environmental requirements could possibly be developed.

A full assessment of in-situ leaching for eliminating the production of solid tailings in new uranium operations is therefore warranted. Studies would need to be initiated with respect to extraction processes and hydrogeology aspects for potential sites. The potential for uranium development in northern Saskatchewan would seem to justify such investigations.

3.9 Reclamation

The use of surface disposal sites for uranium tailings impoundment has led to the requirement for reclamation studies to be done to establish some form of cover, whether vegetative or physical, for minimizing the release of contaminants to the environment.

The main objectives of a reclamation cover are:

- to provide a reduction of infiltration by precipitation by reducing seepage and enhancing surface runoff.
- to minimize radon emanation and gamma radiation.
- to ensure the integrity of the cover over the long term.
- to return the land to its original use as much as practically possible.

The constraints of reclamation include the physical environment of the site, both in terms of local availability of materials and climate, and the radiological and physical characteristics of the tailings to be reclaimed.

The method of vegetation as a reclamation cover for acid-generating tailings in the Elliot Lake area has been established

and well proven at the Nordic tailings site. To date this vegetation cover has not indicated any reduction in seepage values but the problem of wind erosion of tailings has virtually been eliminated. Further work is planned to investigate the potential for water uptake by trees on tailings surfaces. This is expected to provide a two-fold increase in water uptake and thus a reduction in seepage may eventually result with the encroachment of indigenous vegetation.

The establishment of natural vegetation at abandoned sites of neutral tailings has been well exemplified as described in Section 2.

The use of soil covers on tailings is practiced in the U.S. where local soils are more readily available. The various soil covers used include glacial till, cohesionless sands, cohesive clays and rip-rap covers of local or waste rock. The clays are more effective in controlling radon emanation when placed in sufficient thickness and their low permeability provides the added benefit of seepage reduction. The sands however are less susceptible to cracking and hence are useful as a top layer over the impermeable clays. The long-term integrity of surface covers can be enhanced by vegetating or the use of a rip-rap cover as a final placement. Cover thickness would need to be adequate to prevent root penetration by the vegetation cover.

Artificial covers can also be used. These include concrete, asphalt, plastic membranes, fabric underlayments or sprayed chemicals. Due to degradation by weathering these cannot be considered practical for long-term abandonment.

The use of natural soils as covers for abandoned tailings in the Canadian uranium mining areas is not practical due to

the lack of locally available suitable material. A glacial till cover was tested at the Lower Williams Lake tailings area in Elliot Lake and vegetation results were excellent but reclamation costs were approximately \$14,000/ha (1978). A rip-rap cover of waste rock is being used in the close-out of tailings at Madawaska but again the availability of waste rock may not be adequate at all sites. Also the radon attenuation properties of a rip-rap cover of rock are probably minimal.

The possibility of using pyrite-free tailings as cover material for abandoned tailings has been discussed in Section 3.7.4. If the construction of an acid plant becomes a reality in Elliot Lake then this may become a suitable alternative for use as a reclamation cover on existing and abandoned tailings.

The use of waste products such as sewage, composted garbage, sawdust, barkfines or wood chips as surface cover has been investigated but the lack of supply of this type of cover material may not make it practical. They have been mostly considered as an aid for establishing vegetative covers.

The use of a water cover to reduce pyrite oxidation has been discussed in Section 3.3. The viability of this as a reclamation option is exemplified by the establishment of flooded communities with its inherent vegetation at several abandoned sites in Canada. Due to the relative success of these tailings surface establishments they should be encouraged where site conditions are conducive to this type of indigenous cover.

As discussed previously reclamation and close-out plans need to be included in the initial planning stages of a uranium project. On this basis the tailings impoundment selection

and the tailings placement methods will have a governing effect on the ultimate reclamation methods to be used. Some items which can be seen as accelerating reclamation procedures on close-out include:

- the use of filtered, thickened or layered tailings deposition along with suitable underdrains to increase consolidation.
- the placement of a coarse tailings layer or pyrite-free tailings as a final cover.
- the addition of solidification chemicals to the mill tailings in the final period of operation.
- the addition of organic nutrients and fertilizers in the tailings pulp for areas of final deposition.

It is obvious that further investigations will need to be carried out to establish the most suitable cover for the long-term abandonment of existing surface tailings. Further research may be warranted for developing more adaptable vegetation for tailings reclamation and for determining requirements for physical surface covers, but the main area of attention will deal with pathways analysis for the various reclamation options available.

3.10 Waste Rock

Some waste rock originating from the mine operation has the potential for impact on the environment due to the possible content of trace levels of contaminants as well as acid-generating potential due to the presence of minor amounts of sulphides. This can cause release of contaminants to the environment if proper storage or disposal is not practiced.

In northern Saskatchewan waste rock with potential for impact on the environment ("special waste") is contained in storage areas which are lined with appropriate materials to collect

any seepage or runoff from the waste piles. This contaminated water is treated or used in the mill process.

At Denison in Elliot Lake waste rock is used underground and any waste that reports to surface is used for building dykes in the tailings area. At the Rio Algom operations all the waste rock is dumped in storage areas at the waste management sites. The normal practice is to store the waste rock at the tailings area or at slightly higher elevation in order for any leachates to be collected in the tailings area.

Although waste rock will likely remain stable over long periods of time, the leachate problems that exist at the Gunnar property in northern Saskatchewan indicates that some problems may be expected in the long-term. Current practices of waste rock containment should therefore be continued at existing and future operations. Surface runoff should be diverted around waste piles and the final slopes should allow some form of reclamation (inert soil cover) and vegetation.

The modelling program will be able to provide information as to the long-term potential environmental effect of waste rock from uranium operations. Some of the research developed for solids disposal technology may become applicable to the long-term containment of waste rock piles or areas.

4. RESEARCH RECOMMENDATIONS

4.1 Introduction

The description of tailings sites given in Section 2 and the outline of waste disposal technologies provided in Section 3 can provide some insight into potential avenues of investigation for arriving at procedures for the long-term close-out of uranium tailings. This information has provided research suggestions for the waste disposal component of the N.U.T.P.

The main areas and topics which can be considered for research have been categorized according to the various components or options of tailings disposal technology.

Due to the site-specific nature of uranium tailings in Canada some of the research suggestions will be site-specific to certain areas of tailings sites. Others may be more generic in nature and may therefore be applicable to more than one type of tailings area.

Although not specifically part of the scope of this report it is becoming apparent that some form of scientifically-based guidelines will need to be defined in order to provide the proposed modelling program with some type of benchmark for assessing the severity of uranium mine and mill wastes.

A list of potential research avenues is detailed below. It should be noted that they are not listed in any particular order.

4.2 Solids Disposal

The suggested areas of investigation for surface and subsurface disposal are:

- provide test programs which will increase the knowledge of in-pit disposal close-out strategies by attempting to quantify the potential for groundwater contamination. Inactive sites such as the Gunnar Pit or the Cluff "D" Pit may provide some insight into this.
- provide programs which would compare the efficiencies of lined pits (Union Carbide Gas Hills operation) vs. pits with porous envelopes (Collins Bay Project) with respect to potential groundwater contamination.
- promote the use of mine backfill techniques for tailings disposal by investigating various aspects such as increase use of slimes by solidification, radon emanation, stabilizing additives, drainage and consolidation improvement and mitigation measures for preventing groundwater contamination. An experimental backfill program could possibly be set up for this purpose.
- provide programs which will allow a field demonstration of deep, or shallow, lake disposal of tailings where physical and chemical variables can be monitored for determining the viability of this option. Abandoned sites such as Olive Lake, Panel Dam A or Lorado could be used for this purpose.
- continue the assessment of the layered tailings concept by maintaining present test experiments and obtaining a geotechnical and chemical assessment of the results. In conjunction with this work, attempt to determine the discontinuity effect of winter deposition layers. Provide assistance to a monitoring program for the layered tailings area at Key Lake in order to obtain field data for comparison with conventional tailings deposition methods and arriving at long-term recommendations.
- assess the permeability and long-term stability of dams for recommending construction methods for the long-term close-out of surface tailings sites.
- determine the effect of tailings and fine precipitates in river and creek basins at distances away from tailings sites.

- through field experimentation and monitoring assess the efficiency of subsurface barriers for providing effective seals of below-ground contaminants.

4.3 Seepage

Areas of interest for seepage studies include:

- evaluate the physical and chemical properties of the various impoundment liners with respect to long-term stability and integrity under the load stress of tailings and the effect of various qualities of seepage on liner efficiencies.
- assess the chemical aspects of radionuclide dissolution in tailings and the mechanism for radionuclide migration.
- develop and increase the understanding of the re-adsorption effect of soils on radionuclides and other contaminants and determine total capacity factors for the various subsurface media at tailings sites.
- assess the possibility of in-situ treatment of groundwater in the vicinity of tailings sites by borehole injection of appropriate mitigating solutions and chemicals.
- determine the geochemical mechanism which can cause attenuation of contaminants during migration through fractured rock.
- assess the use of a limestone base as buffering capacity for seepage beneath tailings impoundment areas.
- study soil profiles of various tailings areas where subsurface mitigation of contaminants is occurring in order to provide improvements for future tailings site selection.
- assess the efficiency of tailings slimes or fine precipitates on the reduction of seepage at the bottom of tailings area.
- provide further information on the possible reduction of radium dissolution by the elimination of ammonia in tailings water.
- determine the effect of the phreatic surface in the tailings mass as a function of contaminant release.

- quantify the beneficial effect of sodium chemical additives for improving the impermeability of clays.
- assess the long-term dissolution potential of heavy metal and arsenic precipitates in northern Saskatchewan tailings.

4.4 Radionuclide and Pyrite Removal

Research in radionuclide and pyrite removal should continue in the following areas:

- continue assessments for selective removal of environmental contaminants in tailings for separate long-term storage in stable areas.
- determine disposal methods for the concentrated, high-activity, waste products originating from radionuclide removal from uranium tailings.
- continue research to provide a leaching agent which will dissolve all radionuclides from uranium ores. Chloride metallurgy is one option which seems to warrant continued investigation.
- develop methods for selective purification and recovery of contaminants from the leach liquors.
- develop circuits for recycling of lixiviant solutions to make potential processes more economically and environmentally viable.
- assess the use of sodium chloride for leaching radium directly from tailings in existing processes.
- assess the use of nitric acid for northern Saskatchewan ores with low pyrite content.
- assess pyrite removal for acid production in the Elliot Lake area in terms of radionuclide contamination in process water, in the acid product and in exhaust gases.
- carry out cost estimates for pyrite removal/acid production for comparison to long-term reclamation costs of acid-generating tailings.

4.5 Effluent Treatment

Effluent treatment and waste sludge research suggestions include:

- provide research for improving dewatering methods of waste sludges.
- investigate disposal methods for long-term isolation of waste sludges.
- assess other potential radium removal methods such as barite, carbonatite, ion exchange and reverse osmosis.
- assess the long-term re-dissolution potential of waste sludges under separate storage in settling ponds and as mixtures with solid tailings.
- arrive at permanent disposal methods for waste sludge in existing settling ponds and in dedicated containment lakes.
- promote the use of mechanical clarification methods for treated effluent by providing comparisons between settling basins and existing mechanical installations.
- determine effluent (seepage and runoff) treatment conditions which will be applicable on close-out of the proposed northern Saskatchewan tailings sites. The present layered tailings test pit at Ontario Research Foundation could be used to present a "worst case" situation with respect to seepage and runoff.

4.6 Modification

Research needs in this area include:

- carry out test programs for assessing the use of physical sand/slime separation methods as a beneficiation method. This can be done in conjunction with enhancing the layered tailings concept, in conjunction with the agglomeration of slimes for underground backfill and for providing acceptable surface covers for reclamation.

- define the physical properties of solidified tailings with respect to long-term weathering.
- investigate the efficiency of chemical fixation of contaminants.
- investigate potential additives in tailings for reducing permeability.
- assess potential consolidation methods for active and inactive tailings sites.
- further assessments of ore beneficiation combining various physical methods may be warranted.

4.7 In-situ Leaching

This alternative to conventional mining and milling should be assessed thoroughly by carrying out the necessary test programs and hydrogeological investigations to provide design criteria for a potential field trial. If environmental concerns can be satisfied, a field trial should be carried out at a suitable northern Saskatchewan site in conjunction with interested operators.

4.8 Reclamation

Items of interest for reclamation include:

- determine the efficiency of natural and artificial covers and vegetation on such aspects as infiltration of water, radon attenuation, gamma radiation, long-term stability and potential reduction of seepage and leaching of contaminants.
- determine the amount of acid generation in upper layers of pyrite tailings and assess the efficiency of various covers on minimizing acid generation.
- assess the use of pyrite-free tailings as a reclamation cover for abandoned tailings and for currently active tailings.
- determine the optimum cover, at minimum cost, for the various site-specific areas of abandoned tailings.

- determine the close-out potential of a water cover on tailings with respect to long-term efficiency for mitigating acid generation and radon release. Currently abandoned sites would be well-suited for a field investigation of this option.
- determine the optimum moisture content of tailings for good moisture control conducive to reclamation.
- further work is required on radionuclide uptake by plants and on possible mitigative measures.
- determine the effect of root penetration on the efficiency of vegetated covers.
- assess the effect of reclamation procedures on abandoned tailings sites which are currently in equilibrium (i.e. Lorado)
- arrive at an understanding of natural plant successions and soil development and use natural ecological processes that are on-going as a guide for the natural reclamation of abandoned tailings.
- assess the development of wetland communities as a long-term reclamation option for site-specific tailings sites.
- develop areas of investigations where natural processes can be encouraged for reclamation.

4.9 General

Some general suggestions include:

- the proposed tailings sites in northern Saskatchewan should be monitored closely to assess, in the field, the applications of layered tailings and in-pit disposal for tailings management.
- abandoned sites in the Elliot Lake area and in northern Saskatchewan should be monitored to increase the knowledge of tailings sites with respect to natural mitigative measures that may be occurring.
- the capital and operating costs of various waste management options should be determined. This would include potential mill process alternatives.

- groundwater monitoring programs should be carried out where information on subsurface effects is required with respect to horizontal and vertical mobility of contaminants.
- the proposed close-out modelling studies for the Cluff Lake operation should be assimilated into the N.U.T.P. program and used in conjunction with some of the suggested research investigations.
- the different close-out requirements should be determined for non-acid generating tailings and for pyritic tailings.
- investigations should be carried out to maximize the recycle of tailings water in existing and proposed mill operations.
- the correlation of laboratory or pilot-scale tests to field information should be accomplished where possible in order to assist in long-term predictions.
- available field data should be obtained from other uranium tailings sites in the United States, Australia and South Africa for use in modelling programs and in providing direction for disposal technology research.
- set up test programs to determine the contaminant release potential of waste rock from various mine sites in order to determine the long-term effect of this material on the environment. Compare test results to actual field measurements at the Gunnar site or the new Key Lake site.

5. PROGRAM SUGGESTION

The variety of research options suggested above will require the use of the proposed modelling program for a preliminary assessment of the many research avenues available. This will then provide information which will allow priorities to be set from which a detailed research program on disposal technology can be outlined.

Nevertheless the assimilation of the information in this report can provide some insight into areas of disposal technology for which investigations should be initiated at the onset of the program. Although a panel review would be more appropriate for assessing priorities the following personal viewpoints are presented.

The long-term erosion potential of surface tailings suggests that the use of sub-surface tailings disposal would provide a more permanent disposal option which could meet the requirements of long-term abandonment. Therefore research in this area should take precedence over other disposal methods in light of the many unknown aspects of below-ground tailings. The aim of the research in this area should be to promote the use of mine backfill, increase the technical knowledge of in-pit disposal and assess the potential of deep lake disposal.

The potential of layered tailings as a surface disposal option with respect to minimizing or eliminating long-term seepage provides justification for continued efforts in this area. Research should be oriented as detailed in Section 4.2.

The requirement for the use of liners in tailings containment areas necessitates the need for assessing the long-term physical and chemical characteristics of available materials with respect to tailings load stress and potential detrimental effects by seepage solutions.

The potential for long-term mitigation of contaminant release by natural soils, and clay liners, should be investigated with respect to the physical and chemical interactions that take place.

The benefits of innocuous tailings for long-term disposal justifies continued research on radionuclide removal. This work should be restricted to in-mill process options which have the potential to be economically viable compared to existing processes. More efforts should be spent on finding methods for permanent disposal of the high-activity concentrated waste products from such processes. It should be realized that any new novel process will only be applicable to future uranium operations, thus research on leaching radionuclides from existing tailings should be considered as low priority.

The long-term environmental concerns of acid generation and resultant radionuclide mobilization in pyritic tailings underlines the importance of research in this area. The application of pyrite removal for Elliot Lake operations should be pursued with respect to current studies on acid production from pyrite concentrates. Research on preventing pyrite oxidation in abandoned tailings by reclamation covers or by the use of flooded tailings should form part of the initial stages of the disposal technology program.

The problems of waste sludge should be addressed with respect to potential long-term re-dissolution and for assessing disposal methods with long-term isolation potential.

The alternative of in-situ leaching for northern Saskatchewan deposits remains as a potentially viable method of uranium extraction due to the elimination of tailings disposal requirements. Necessary test programs should be initiated to assess this alternative and to address the associated environmental concerns.

Reclamation studies must be continued along with field monitoring programs to arrive at site-specific procedures for long-term reclamation of abandoned tailings sites. The study of natural, ecological reclamation processes that are occurring on surface and below ground at abandoned sites should be used as a guide to develop reclamation plans. The development of wetland communities should be assessed with respect to its long-term effectiveness as a reclamation option.

6. REFERENCES

- Blakeman W., Environment Canada, Ottawa, verbal communication.
- Boyce T.D., Boom S., "Removal of Soluble Radium from Uranium Minewaters by a Selective Complexer", SME-AIME Annual Meeting, Dallas, Texas, February 1982.
- Bragg K., Potter C., James A., "Recent Developments in the Regulation and Management of Canadian Uranium Tailings", IAEA-SM-262/1.
- Campbell D.B., "The Stability of Waste Rock Pits and Leachate Control Associated with Uranium Mining", First International Conference on Uranium Mine Waste Disposal, May 1980, Vancouver, B.C.
- Cherry J.S., "Mobility in Groundwater of Contaminants from Uranium Mill Tailings", Uranium 1982, Toronto, Ontario.
- Collins Bay B-Zone Development "Environmental Impact Statement", June 1981.
- Eldorado Nuclear Limited, "Decommissioning of the Beaverlodge Mine/Mill Operations and Reclamation of the Site", June 1982.
- Environmental Assessment Board, Final Report, Elliot Lake, Ontario, May 1979.
- Hanney K.E., Jurgens E.I., Comrie D.C., Fletcher R.H., "Reclamation Concepts and Practice for Uranium Tailings Impoundments", First International Conference on Uranium Mine Waste Disposal, May 1980, Vancouver, B.C.
- Haque K.E., "Aqueous-chlorine Leaching of Typical Canadian Uranium Ores", Uranium I, 1982.
- Haw V.A., "The Canadian Research Programme into the Long-term Management of Uranium Mine Tailings", IAEA-SM-262/13.
- Heymann L., "The Close-out of the Waste Management System at Agnew Lake Mines", Uranium 1982, Toronto, Ontario.
- Itzkovitch I.J., Ritcey G.M., "Removal of Radionuclides from Process Streams - A Review", CANMET Report 79-21, April, 1979.
- Kalin M., "Identification of Potential Environmental Problems at Port Radium", 1983, prepared for Environment Canada.
- Kalin M., "Environmental Conditions of Two Abandoned Uranium Mill Tailings Sites in Northern Saskatchewan", prepared for Saskatchewan Environment, 1982.

Kalin M., "Long-term Ecological Behaviour of Abandoned Uranium Mill Tailings I. Synoptic Survey and Identification of Invading Biota". Institute of Environmental Studies, University of Toronto, Toronto, Ontario, 1983.

Kilborn, Beak Report "An Assessment of the Long-term Behavior of Present and Proposed Methods for the Management of Uranium Mill Tailings", AECB Report INFO-0024, July, 1979.

Meadley T., Cluff Mining verbal communication.

Melis L.A., Fraser K.S., Lakshmanan V.I., "The Midwest Uranium Project - Development of the Milling Process", Uranium, 1982, Toronto, Ontario.

Murray D., Webber B., LaRocque, E., "Reclamation of Lower Williams Lake Tailings Area of Denison Mines Limited", CANMET Report MRP/MRL 78-1.

Philipps C.R., Poon Y.C., "Status and Future Possibilities for the Recovery of Uranium, Thorium and Rare Earths from Canadian Ores, with Emphasis on the Problem of Radium" Minerals Sci. Engng, vol. 12, no. 2, April, 1980.

Pullen P.F., Davis J.B., "Description of the Panel Mine Tailings Area Rio Algom Ltd., Elliot Lake, Ontario, Canada", NEA Workshop, Colorado State University, Fort Collins, USA, October, 1981.

Ritcey G.M., Silver M., "Lysimeter Investigations on Uranium Tailings at CANMET", CIM Bulletin vol. 75, no. 846, October, 1982.

Robertson A.M., van Zyl D.J.A., "Designated Construction Options for Surface Uranium Tailings Impoundments", First International Conference on Uranium Mine Waste Disposal, May 1980, Vancouver, B.C.

Robinson D.J., Ruggles R.G., Zaidi A., "A Study of Water Pollution in the Vicinity of Gulf Minerals Rabbit Lake", 1978, prepared for Environment Canada.

Ruggles R.G., Robinson D.J., Zaidi A., "A Study of Water Pollution in the Vicinity of Two Abandoned Uranium Mills in Northern Saskatchewan", 1978, prepared for Environment Canada.

Ryan R.K., Levins D.M., "Extraction of Radium from Uranium Tailings", CIM Hydrometallurgical Meeting, Toronto, Ontario, November 1979.

Scarano R.A., "Review of Uranium Mill Tailings Management Programs Involving Below Grade Disposal", First International Conference on Uranium Mine Waste Disposal, May 1980, Vancouver, B.C.

Sharma H.D., Ministry of Environment, Ontario, verbal communication.

Sirois L.L., Cristovici M.A., Raicevic D., "Preconcentration of Uranium Ores", Uranium 1982, Toronto, Ontario.

Sutherland D., Environment Canada, Yellowknife, verbal communication.

Swanson S., Abouguendia Z., "The Problem of Abandoned Uranium Tailings in Northern Saskatchewan - An Overview", SRC Report No. C-805-48-C-81, November, 1981.

Tones P.I., "Limnological and Fisheries Investigation of the Flooded Open Pit at the Gunnar Uranium Mine", SRC Report No. C-805-10-E-82, February 1982.

Whiting J., Christiansen E., Heuser H., Kermeen J.S., Maathius, H., Machibroda P., "Summary Report on the Surface Water and Groundwater Investigations of the Lorado Mill Area and Meteorology Data of the Gunnar Uranium Tailings", SRC Report NO. E-820-4-E-82, March 1982.

Wiles D.R., "The Leaching of Radium from Beaverlodge Tailings", Carleton University, Ottawa, Canada.

National Technical Planning Group, "Report on Uranium Tailings Research", Energy, Mines and Resources, Canada, September, 1981.